TWO CYCLES OF FULL-SIB RECURRENT SELECTION FOR DROUGHT TOLERANCE IN TROPICAL CORN

By

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Dedicated to my parents, and my wife Jocelyne,
for their sacrifices and moral support, and
to the struggle of the Haitian People.

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TWO CYCLES OF FULL-SIB RECURRENT SELECTION FOR DROUGHT TOLERANCE IN TROPICAL CORN

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Breeding maize (Zea mays L.) for drought tolerance is essential to achieve stable yields in water-limited environments. A full-sib recurrent selection program was initiated (1991-1993) at the University of Florida to improve the drought tolerance of a tropical maize population within the multiple cropping systems of Florida. Two cycles were completed with respective selection intensity of 15% and 11%. Selection was made for high grain and total dry matter yields under the irrigated environment, and for high grain yield, reduced total dry matter (TDM), tassel weight, leaf canopy temperature, plant and ear height, drought susceptibility index, and high leaf area duration under the rainfed site. Selected synthetic populations, one from each water regime, were developed after each cycle. Response to selection was evaluated in 1993 by comparing the populations representing

cycles 0, 1, and 2 for each water regime, under a combination of three planting dates (March, May, July) and two water regimes (irrigated and nonirrigated).

Genetic variability existed for yield and the other traits measured for continued progress under the irrigated and nonirrigated conditions. For grain yield, heritability estimates were 0.65 and 0.57 in 1991, and 0.59 and 0.47 in 1992 for the irrigated and rainfed sites, respectively. The corresponding heritability values for TDM were 0.67 and 0.63 in 1991. Linear responses cycle^{-1} for grain yield were 606 kg ha^{-1} (7.22%) and 153 kg ha^{-1} (2.55%) with the irrigated selections tested with and without irrigation, respectively. The corresponding responses were -224 kg grain yield ha^{-1} (-2.67%) and 9.50 kg ha^{-1} (0.16%) cycle^{-1} for the rainfed selections. TDM increased by 0.90 ton ha^{-1} (4.97%) and 0.65 ton ha^{-1} (3.59%) cycle^{-1} for the respective irrigated and rainfed selections tested under irrigation. Harvest index increased by 2.22% and 1.19% per cycle for the irrigated selections tested with and without irrigation, respectively. A gain of 5.95% was obtained by testing the nonirrigated selections under rainfed conditions due to a decrease in TDM. Syn 3I (final irrigated selection) outyielded Syn 3NI (rainfed selection) under high-yielding environments, but both performed similarly under poor environments. Further progress is possible and warranted, particularly within the rainfed population, to increase its potential under rainfed plantings.

CHAPTER I
INTRODUCTION

Maize (Zea mays L.) is the world's most widely distributed crop with more than 134,000,000 ha yielding over 451 million metric tons (FAO, 1981). Maize grows over a wider geographical range and over a wider range of environments than any of the other cereals (Misovic, 1985). It is grown from latitude 58 degrees N in Canada and the USSR to 40 degrees in the southern Hemisphere. About 60 million ha is covered with tropical maize, with the majority being rainfed and low-input, and producing maize as a subsistence food. Economic development and infrastructure play a major role in determining the type of cultivars grown in a particular area of the world. Advanced maize production areas prioritize hybrids, whereas improved open-pollinated materials, some synthetics, and few hybrids predominate in the developing countries (Hallauer, 1987; Fehr, 1987).

Smaller yields are usually registered in tropical latitudes than in the temperate maize-producing areas. Besides limitations due to the sink capacity of the tropical materials (Aluko and Fischer, 1987), other challenging stresses (water, high temperature, mineral, among others), deserving particular attention, characterize this low-input

environment. However, comparing the yield increases in the developed and developing countries in the past 25 years, plant breeding strategies for tropical maize improvement have accomplished little on the average over this period. Release of reliable disease resistant cultivars has been the most important success.

Drought, arising from irregular rainfall distribution and low water-holding capacity of soils, is a factor influencing both temperate and tropical maize yields. Misovic (1985) mentioned that selection for drought resistance is not conducted in the major areas of the Corn Belt because existing rainfall patterns do not consistently allow the level of drought stress needed for making effective selections. Escape, through crop maturity, planting dates, and irrigation is still considered the most efficient means to use in breeding tropical (Fischer et al., 1983) and temperate maize (Jensen, 1971; Jugenheimer, 1976) for drought resistance. By selecting under drought-prone environments, some of the potential yield is sacrificed in return of improved stability under stress. Average losses of 15% for tropical maize production due to water stress had been reported (Brewbaker, 1985) and the high frequency of drought often limits the inputs that could enhance yields (Fischer et al., 1983), and explains much of the mixed cropping or double-cropping with maize in the tropics (Arias and Gallaher, 1987).

Lack of drought resistance is a significant problem of tropical regions, where often a drought period occurs even during the rainy season. Low capacity of moisture retention by the soil makes even a short period of drought a constraint in the crop growth, thus limiting grain production, particularly if the drought period coincides with flowering and pollination time (Robins and Domingo, 1953; Claasen and Shaw, 1970). The problem of drought resistance is much more serious in the semi-arid tropics where lack of rain in the growing season may extend for longer periods and the crop may be completely lost. Periodic occurrence of short-term drought is very common during the corn growing season.

Flowering and grain filling are the critical periods when water deficits most significantly reduce corn yields. Yield losses of 25% have been reported from a 2-day wilting period (Brewbaker, 1985). Stresses like high temperature, soil toxicities, acidity, and salinity, are often combined with water stress, and are particularly severe during pollination when water demands are highest. Improved maize tolerance for drought stress is quite essential for tropical maize improvement (Bjarnason et al., 1985). Variation exists among genotypes in susceptibility to water stress, which suggests that the drought tolerance/resistance trait can be improved (Fischer et al., 1983; Jensen, 1971).

Population improvement has been proven to be a powerful breeding tool for genetic improvement of maize. Some

researchers (Gardner, 1978) have even mentioned that better yield increase would have been realized, had this tool been used. The Maize and Wheat Improvement Center (CIMMYT) and the International Institute of Tropical Agriculture (IITA) are two institutions extensively using population improvement for breeding tropical maize. Through recurrent selection, good genetic gains per cycle (2.4%) were achieved for reduced plant height of 'Tuxpeno', a tropical population, (Johnson et al., 1986). Associated traits, such as time to anthesis, anthesis-to-silking interval, stem lodging, harvest index, and grain yield per unit area were also improved.

Recurrent selection is a breeding method which increases the frequency of favorable alleles for the trait under selection in a maize population. Recurrent selection is conducted in a repetitive manner (including development of progenies, evaluation of progenies, and recombination of superior progenies) to increase the mean and maintain the genetic variability of the population to allow continued selection (recombination is achieved by the intercrossing of selected genotypes between cycles of selection). This method has been effective in improving grain yield in both self and cross-pollinated crops, such as maize (Hallauer and Miranda, 1988), and soybean [*Glycine max* (L.) Merrill] (Piper and Fehr, 1987). This method has recently received greater interest than in the past, as the need for broadening the genetic base of breeding programs is increasing.

Recurrent selection provides a means for the systematic genetic improvement of genetically broad-based germplasm sources in breeding programs and, at the same time, permits the development of new lines for use in hybrids. Concurrent improvement in harvest index, in grain-filling period and in delayed plant senescence has been obtained with improvement of maize grain yields (Bregitzer et al., 1987)

Misovic (1985) indicated that breeding strategy, selection criteria, and efficient methods that would allow maximum progress in a short time are critically important for the developing world. The development of cultivars with greater resistance to drought, high temperatures, soil toxicities, acidity, and salinity seems to be the most important maize breeding strategy for tropical conditions.

Specific Maize Situations

The interest in double cropping corn in North Florida, encouraged by the long warm growing season, subjected this crop, either tropical or temperate, to different environmental stresses such as drought, insects, heat, and diseases. Jordan (1984) reported an average rainfall of 1270 mm to 1372 mm year^{1}. However, many areas are facing water scarcity or water allocation conflicts (Maloney et al., 1980).

To avoid the rainfall deficit months of April and May in North Florida, corn is often planted late March and early

April (Horner et al., 1959), such that the tasseling and grain filling periods coincide with the summer rains. However, earlier plantings (late February or early March), when compared to several later plantings, have resulted in best yields only when irrigated (Horner et al., 1959; Gallaher et al., 1986; Edme, 1990). The low retention capacity of the sandy soils prevailing in North Central Florida requires frequent irrigations in order to satisfy the water demand of corn for the growing season (Prine et al, 1975).

Breeding programs in Gainesville have dealt primarily with insect resistance, disease resistance, maturity, and/or yield potential. Breeding corn for drought and heat resistance is lacking and may be an interesting component in the materials used in North Central Florida, if performance in late summer is of interest.

Irrigation systems are not readily available everywhere corn grows. The problem of drought is serious where the lack of rain in the growing season may extend for longer periods. Planting is delayed, or the later growth or reproductive phases of the crop (which may be completely lost) are not guaranteed when early planting is allowed.

The obligatory rotation in many farming systems of developing countries involves sorghum (Sorghum bicolor L. Moench) after corn (Arias and Gallaher, 1982; Edme and Yates, 1986). Since corn is usually priced higher than sorghum, the development of drought-resistant corn cultivars for these

drought-prone areas would be a viable objective, while other attempts towards this goal are being considered.

CHAPTER II
BREEDING FOR DROUGHT TOLERANCE

Breeding Approaches

Two main questions are usually raised when maize (*Zea mays* L.) or other crops is bred for improved resistance to environmental stress, or for a moisture-deficit environment. The reviews of these two major breeding strategies are given by Blum (1979). The first one relates to whether selection should be carried out under high-productivity environments (Daday et al., 1973) or under stress conditions (Falconer, 1981) with subsequent testing of the selected materials in the target environment. This approach postulates that crop varieties selected under optimal conditions will behave relatively well under suboptimal conditions. Several studies (Roy and Murty, 1970; Mederski and Jeffers, 1973) reported successful selection of cultivars under optimal conditions for performance under suboptimal conditions.

Russell (1974) reported that the experiments in maize breeding in the US Corn Belt have demonstrated the importance of improved yield potential in improving yields over a wide range of environments. Pfeiffer (1987), working with soybean [*Glycine max* (L.) Merrill], obtained a greater selection response from an early planting than from a later heat-

stressed planting. Johnson and Frey (1967) reported higher heritabilities for yield under optimal growing conditions than under low yielding environments. Arboleda-Rivera and Compton (1974) obtained a higher efficiency by selecting maize in the rainy season than in the dry season, with the selected synthetic yielding better in the low-yielding site.

Other researchers (Srivastava et al., 1983; Boyer and McPherson, 1975; Buddenhagen, 1983)) emphasized that the selection of cultivars for use in low-yielding conditions should be conducted in conditions similar to those under which they will be later grown. In other words, superior varieties for drought-prone environments should be selected in situ, that is, under moisture-stress conditions. However, breeding in a low productivity environment results in a slow progress, and requires the testing of large populations. The slow progress is associated with the greater variability found in drought-prone environments. The consequence is a reduction of the efficiency of the breeding program.

Few studies have addressed the problem of determining the best type of selection environments to be used for greater yield in low-yielding sites. However, Wallace et al. (1972) and Falconer (1981) suggested that potential yield and drought resistance must be considered as separate traits, controlled by separate and distinct genetic systems.

The second breeding strategy relates to the reliability of direct selection for yield as compared to the selection of

other morphological and/or physiological traits assumed to be associated with increased yield under stress conditions. Some breeders believe that yield per se is a poor indicator of drought resistance and that a greater progress can be achieved by selecting other traits specifically adapted to drought tolerance, assuming that the traits selected do not decrease yield in better environments (Richards, 1982). However, direct selection in a stress environment most often decreases yield in good conditions. Another third approach mentioned by Blum (1979) involves the incorporation of drought-resistance traits into cultivars with high yield potential for better adaptation to suboptimal conditions.

Drought Effects on Maize

Water stress develops in the plant as the demand exceeds the supply of water. Drought along with temperature is the main environmental factor influencing the growth, performance and the yield levels of maize across the world (Boyer, 1982). The response of maize to water deficits has been investigated in many studies (Sinclair et al., 1990; Westgate and Boyer, 1986). Marked effect on grain yield occurred particularly around tasseling (near or at anthesis) (Slabbers et al., 1979; Shaw, 1974). In the tropics water stress, occurring even during the rainy season, is detrimental to maize grain yield. Escape by irrigation, crop maturity, and planting date has been proposed as the most efficient method to reduce the

effects of drought (Kassam et al., 1975). However, drought is not predictable, and as a result, escape is not quite effective in areas where the unavailability of water is systemic.

Leaves of the maize plant are usually severely damaged by drought. Leaf firing, excessive delay of anthesis-to-silking interval, and dry matter losses are the most detrimental effects of drought reported (Fischer et al., 1983; Jensen, 1971).

In some crops, such as maize, sorghum (Sorghum bicolor L. Moench), and various legumes, leaf firing is an evident symptom of water stress, resulting from an insufficient cooling during transpiration and the subsequent heating of all or part of the leaf to lethal temperatures (Fischer et al., 1976; Castleberry, 1983). Leaf rolling, induced by the loss of turgor, is a most familiar response to water deficit, especially in cereals.

Since the leaf is directly involved with the production of assimilates for growth and yield, leaf-water potential is the common immediate measure of plant water stress. As water deficit develops, both water potential and osmotic potential are reduced at differing rates (Salisbury and Ross, 1985). Accumulation of solutes during the development of water deficit, defined as "osmotic adjustment" or osmoregulation, allows the maintenance of a higher turgor potential at a given

leaf-water potential. Osmotic adjustment positively affects growth and yield under stress.

Water deficit has wide repercussions on plant growth, development, and economic yield. Depending on the intensity and duration of water stress, senescence of leaves, reduction of leaf area, reduction of crop water use, stomatal closure, and cessation of plant growth are different steps in the manifestation of drought stress.

The content of some plant hormones, most notably abscisic acid (ABA), increases in leaves under the effect of water deficit, causing stomata to close. Ackerson (1983), comparing two maize hybrids, found a higher photosynthesis rate in the hybrid with the higher content of ABA. Various metabolites accumulated in the plant tissues upon reduction in leaf-water status (Hanson, 1980). Free-proline amino acid, and betaine were noted to reach relatively very high concentrations under the condition of water stress. In maize, Ishan and Daffling (1982) investigated the changes in ABA and proline accumulation in some resistant and susceptible varieties.

It is critical to apply the knowledge on plant responses to drought to the breeding efforts designed to overcome the limitations that drought imposes on crop productivity. Involvement of plant physiologists in the process is imperative. The use of water stress studies in breeding programs is increasing.

Genetic Variation and Inheritance

Drought resistance is not a simple heritable plant attribute. Many studies have proven that drought resistance is an hereditary trait (Ceccarelli et al., 1987; Langer et al., 1979). The specific components of resistance are therefore considered when addressing the genetic control and the inheritance of drought resistance.

The inheritance of leaf growth characteristics in corn has been the topic of several studies. Cross (1990) detected both general combining ability (GCA) and specific combining ability (SCA) in selecting early maturing maize for rapid leaf expansion. General combining ability was more important for leaf measurements than for grain yield in three separate diallel-cross experiments conducted by Rutger et al., (1971). A high phenotypic correlation of $r = 0.81$ was found between ear leaf area and total leaf area. Uchimiya and Takashi (1973) studied early leaf growth and growth of mesophyll cells of the third leaf blade in maize inbreds and their hybrids. The vigorous leaf growth in the hybrids was due to their higher rates of cell division.

Rood and Major (1981) reported that neither reciprocal effects nor SCA effects were significant for leaf number or leaf development rate in an early maize diallel. Incomplete dominant gene action for increasing leaf numbers and overdominance for leaf area were suggested by Pavlikova and

Rood (1987), working with four early-maturing maize inbreds and their hybrids.

Genetic variation in maize yield response to water stress exists. Significant variation among genotypes was found in maize (Fischer et al., 1982; Jensen, 1983), in sorghum (Garrity et al., 1982; Seetharana et al., 1982), and in wheat (*Triticum aestivum* L.) (Laing and Fischer, 1977; Keim and Kronstad, 1979) by the means of stability analysis.

Genetic variation in leaf-water potential was revealed. Root growth partly influences this ability for maintaining leaf-water potential through extraction of soil moisture. Genetic variability in root growth or size was found in sorghum (Blum, 1979), maize (Fischer et al., 1983), and rice (*Oriza sativa* L.) (Ekanayake et al., 1985). Armenta-Soto et al. (1981) found that in rice long roots and a high root number were controlled primarily by dominant alleles in one parent, but high root/shoot ratio was controlled by either dominant or recessive alleles. Additive and dominance effects contributed to the inheritance of the root attributes and narrow-sense heritabilities were moderate. In sorghum, heterosis was manifested in seminal root length, growth rate of crown-root axes, and total length and volume of crown roots.

Genetic variation for osmoregulation within a species has been indicated for a number of crops (Ludlow, 1980; Johnson et al., 1984). Simple inheritance was proposed but not firmly

established in wheat by Morgan (1983). Stomatal activity is under complex physiological control, including the effect of abscisic acid (ABA). The variation in ABA is apparently under genetic control (Austin et al., 1982). Simple inheritance was demonstrated in ABA accumulation. Genetic variation in canopy temperature under stress was confirmed for maize (Fischer et al., 1976), for soybeans (Harris et al., 1984), and for cotton (*Gossypium hirsutum* L.) strains (Hatfield et al., 1987).

Maize seedling recovery after stress was associated with dominant or recessive genetic variance, depending on the hybrid combination (Williams et al., 1969). Inbreds with high general combining ability produced more drought tolerant hybrids. Variance-covariance regressions indicated that the inheritance of drought tolerance in sweet corn follows a pattern of partial to nearly complete dominance. Working with snap-bean (*Phaseolus vulgaris* L.), Bouwkamp and Smith (1982) found that drought resistance was conditioned by a single dominant gene in one accession and by two genes with epistatic action in the other.

Selection Criteria for Drought Resistance

The development of drought-tolerant varieties involves the screening of certain physiological or morphological traits using laboratory or field screening, combined with simultaneous selection for other desirable plant and grain traits. Drought resistance is a complex phenomenon. Limited

breeding efforts have been placed on drought tolerance per se as a primary breeding objective. A selection index is often used as an efficient way to improve several quantitative traits simultaneously in a population. Crosbie et al. (1980) compared the efficiency of 16 selection indices constructed to improve cold tolerance in maize.

Several reports have dealt with the various physiological and morphological traits and their association with drought tolerance in maize and sorghum (Levitt, 1972; Fischer and Turner, 1978; Fischer and Palmer, 1984; Dow, 1981). Leaf conductance and osmoregulation, leaf size and rolling, leaf water potential, stomatal sensitivity, root growth and soil moisture extraction, heat and desiccation tolerance, abscisic acid, and amino acids are usually investigated for their application in breeding programs.

Leaf rolling had been used as a simple screen in rice at the International Rice Research Institute (IRRI) (O'Toole and Cruz, 1979), where a visual score from 0 to 5 is assigned to various stages of leaf rolling. Leaf rolling and leaf firing may jointly be used in a score for injury by drought stress in maize (Fischer et al., 1983). In that study, the rate of leaf senescence under stress was negatively correlated (r= -0.48**) with yield under stress in a selection program in maize. Rosic (1963) reported drought-resistant maize lines were smaller in height, had thickened stems, had more developed roots, used less water per unit of plant mass, and had fewer stomata

openings. Rosic (1963), and Rosic et al. (1968) used stalk and grain yield, percentage of seed-setting, and grain/stalk ratio as criteria to classify 142 inbred lines for drought resistance in laboratory and field experiments.

A drought index based on yield under both fully irrigated and stressed conditions was used by Fischer et al. (1982) to improve a tropical population (Tuxpeno) for drought resistance through a modified recurrent selection program. This index was the ratio of yield under stress to nonstress, relative to the ratio of the mean yield of all genotypes under stress to nonstress. A selection index had been developed to screen a large number of segregating populations. This selection index included grain yield under irrigation (yield potential) and non-irrigation, flower delay, canopy temperature, leaf area loss during grain fill, and relative rate of leaf elongation (RLE). The selection index was efficient in detecting differences between resistant and susceptible varieties under water stress, but no yield differences were observed under irrigation. Genetic variation existed within this tropical maize population for performance under drought. The inclusion of plant characters in addition to yield enhanced the identification of the drought-resistant families. They concluded that selection for drought resistance may improve grain yield under drought. A 9.5% yield increase per cycle was obtained for a selection pressure of 30%. Remote measurement of canopy temperatures under stress with the

infrared thermometer was also used in the selection index for dehydration tolerance. Significant negative correlations ($r = -0.56^{**}$ to $r = -0.73^{**}$) were found between canopy temperature and grain yield under stress across the selected materials.

Growth under stress in the field may be used as a selection index. Fischer et al. (1982) used the rate of increase in terminal leaf-tip height above the ground over a time interval of one week. Several breeders (Castleberry, 1983; Fischer et al., 1982) also used the time interval between pollen shedding and silking in maize under drought stress as a selection index. Higher-yielding selections had a shorter interval. Bidinger et al. (1982) indicated that variation in phenology within the breeding population has to be accounted for in most tests for drought resistance.

Seedling growth tests are used to screen water stress responses of maize seedlings (Hall et al., 1984; Williams et al., 1969). This is done by growing seedlings in a medium of constant water potential, such as a solution of polyethylene glycol (PEG). Studies on the possibilities of using cell cultures in the selection for drought resistance are just emerging. The procedure involves selection in cell cultures under osmotic stress applied by PEG. The tolerance of cell lines to PEG were not permanent (Handa et al., 1983; Smith et al., 1985).

Proven and established methods are not available as conventional routines in selecting for drought resistance. It is also noted that no trait can be used singly for achieving progress. Several criteria combined into one selection index are necessary for developing drought resistant varieties. Fischer et al. (1982) found that the best association and the greatest selection differential with yield under stress were obtained with canopy temperature.

Additional results by Roy and Murty (1970), and Daday et al. (1973) support the general conclusion that selection for yield and yield components is more effective under nonstress conditions because of greater genetic variance and heritability under these conditions. Stress conditions limit efficiency and progress in selection for yield. Working with large populations under stress will, however, increase the probability of securing superior recombinations in spite of the relatively low heritability (Blum, 1988).

The objectives of this breeding program aimed 1) to improve yield and yield stability of corn under rainfed conditions; 2) to evaluate an array of plant traits for their potential usefulness in a breeding program designed to improve maize grain yield in drought-prone areas; 3) to compare the selections evolved both under stress and nonstress environments; 4) to contrast responses to selection in irrigated and rainfed conditions; and 5) to develop materials as possible sources of drought resistance.

CHAPTER III
MATERIALS AND METHODS

Field Screening

Two cycles of Full-sib recurrent selection for drought tolerance were conducted for the period 1991-1993, at Green Acres Agronomy Farm, of the University of Florida, Gainesville, Florida (29^0 38'). The experimental site was an area classified as Arredondo fine sand (sandy, siliceous, thermic, Grossarenic Paleudult) (Soil Survey Staff, 1984).

Evaluation Year 1991

Plant materials

The base populations were selected from 199 tropical full-sibs (FS) under selection for yield potential. The original populations used to create the 199 FS were derived from different genetic backgrounds (Espaillat, 1990; Gallaher, personal communication). One hundred forty (140) FS out of the 199 were selected for highest yield and used to start the full-sib recurrent selection program for drought resistance. Four other materials were included as checks: two synthetics developed for high yield (R.N. Gallaher, personal

communication), a temperate hybrid (Pioneer brand 3320), and a tropical hybrid (Dekalb XL678-C).

The 140 full-sib families and the four checks were planted on 21 March 1991 (irrigated experiment) and on 22 March 1991 (nonirrigated experiment) at Green Acres in a 12 X 12 partially balanced lattice design with four (4) replications. Plot size was a single row of 3.6 m length and 0.75 m width. One kernel was hand-planted per hill for a plant density of 65,000 plants ha^{-1}. Hills were 0.25 m apart. This initial evaluation trial was designed to measure the variation in a number of plant characters associated with drought-adaptive mechanisms among the 140 full-sib progenies and to determine their potential effectiveness in selection.

Field management

The two sites were uniformly plowed, disked and subsoiled before planting. Carbofuran (Furadan:*2,3-Dihydro-2-dimethyl-7-benzofuranyl methylcarbamate*) was applied at a rate of 11.2 kg ha^{-1} to control soil pests. The sites were heavily fertilized with three split applications of 448 kg N ha^{-1} in the form of NH_4NO_3, 896 kg ha^{-1} of Sul-Po-Mag (K_2SO_4:$MgSO_4$), and 448 kg ha^{-1} of 12-4-8 (N-P_2O_5-K_2O). Atrazine (*2-chloro-4-ethylamino-6-isopropanylamino-s-triazine*) mixed with an emulsifier-adjuvant oil was used as a preemergence herbicide at a rate of 2.2 kg a.i. ha^{-1}. Weed control was complemented with cultivation and hand weeding. Armyworms (Spodoptera frugiperda J.E. Smith) were controlled with sprays of Lannate

[(*Methomyl:Methyl-N-[methylcarbamoyl(oxy)] thioacethimidate*)], at a rate of 2.2 kg ha^{-1} or with Furadan at 100 g m^{-2}).

Irrigation was applied with overhead sprinkler as determined by tensiometer readings to the irrigated site during the growing season with approximately a total of 15 cm of water. The stress site received no irrigation. The irrigated and rainfed sites were hand-harvested on 11 July and 12 July 1991, respectively, after completion of physiological maturity determined as black layer formation (Daynard and Duncan, 1969).

Data collected

The 21 superior families were selected for recombination of each generation. The selections were based on the following traits:

Leaf area index (LAI). Leaf area was based on a 3-plant sample from each plot, calculated from the formula:

LA= (leaf length X max width) X 0.75 (Montgomery, 1911). The leaves were measured between 10 and 17 days after flowering, when leaf area of the crop was near its maximum. Leaf area index (LAI) was calculated by expressing the leaf area as a measure per unit area of land. Families with LAI equal to (irrigated site) or smaller (nonirrigated site) than the population mean were selected.

Rate of leaf initiation (RLI). Rate of leaf initiation was derived by dividing leaf number [final leaf-number minus the 6 leaves present in the embryo (Jones and Kiniry, 1986)]

by the time from germination to tassel initiation (Hunter et al., 1977).

Leaf area duration (LAD). Leaf area retention was measured as the ratio of leaf area at maturity to that at flowering. These measurements were initiated at anthesis and estimated according to the formula of Hunt (1978):

$$LAD\ (days) = (LAI1 + LAI2) \times (T2-T1)/2,$$

where LAI1 and LAI2 are the leaf area indices (LAI) measured at anthesis (T1) and at physiological maturity determined as black layer formation (T2), and (T2-T1) is the interval (d) in days between LAI1 and LAI2. Families with LAD equal to or longer than the population mean were selected.

Plant height. At the time of pollination, plant height was measured from the ground to the base of the flag leaf. Families with plant heights equal to or shorter than the population mean were selected at flowering.

Days to anthesis and to silking. Days to anthesis and to silking were determined when anthers and silks were visible on more than 50% of plants per family. They were established by inspecting each plot three (3) times weekly and scoring five (5) adjacent tagged plants. The number of days from anthesis to silking interval (ASI) was also determined as the interval between pollen shed and silking under stress to evaluate flower delay.

Canopy temperature. Canopy temperature was measured with an infrared thermometer (model Everett). Measurements were

made in the stress treatment prior to flowering under still, sunny conditions, near the middle of the day (between 1100 and 1300 hrs) at intervals of five (5) days. Families with leaf canopy temperature equal to or smaller than the population mean were selected in the nonirrigated site.

Tassel weight. Five to 10 tassels were randomly selected from each plot after complete pollen shed. The tassels were cut about 2.5 cm below the first tassel branch and dried at 70^0 C in a forced air dryer to a uniform moisture content before determining weight (g) of tassels. Families with tassel weight equal to or lighter than the population mean were selected in the nonirrigated site. Selection was carried out for reduced tassel, leaf area, and plant height which may improve yield under severe stress conditions.

Drought susceptibility index. The problem of separating the effect of drought resistance from that of potential yield on the yield performance of a genotype under stress was approached by Fischer and Maurer (1978) through a calculated index of susceptibility. The 'susceptibility index' (DSI) estimates, for each genotype, the rate of change in yield between the two environments relative to the mean change for all genotypes, and was calculated as follows:

$$DSI = [(1 - (Y_d / Y_p)] / [(1 - (X_d / X_p),$$

where:

Y_d is the yield under stress,

Y_p the irrigated yield, and

X_d and X_p are the average yields over all varieties under stress and nonstress conditions, respectively. The term $[(1-(X_d / X_p)]$ is defined as 'stress intensity', and DSI expresses yield stability according to the method of Finlay and Wilkinson (1963). Families with DSI equal to or smaller than the mean were selected in the nonirrigated site.

Yield. Total plant dry weight (total aboveground mass), grain yield, and harvest index (HI) were calculated at harvest on the whole-plot basis. The ears were pulled first for ear weight determination, grain weight, grain moisture, and shelling percent. Grain yield was expressed in kg ha^{-1} corrected to 15.5% moisture. All the plants of the plot were cut later and weighed for total plant dry weight determination. A subsample of stalks was weighed, later dried at 70^0 C in a forced air oven, and weighed again for dry weight calculation. Total plant dry matter was expressed in ton ha^{-1}. Families with grain yield, total dry matter, and HI equal to or larger than the mean were selected.

Statistical analyses

Statistical analyses were performed as for a lattice design. The full-sib families were separated for all the variables tested using LSD at the 5% level of significance. The checks were also included in running the analysis of variance for consideration of the lattice design used. The analyses of the lattice designs were performed using the MSTAT (1989) software package. Selection (eyeball) was based mostly

on high grain and dry matter yield, HI, reduced plant height, and ear height in the irrigated site. The most prominent drought-resistant traits such as low DSI and canopy temperature, high grain yield, total dry matter, HI, LAD, and reduced LAI were used to select the families under the nonirrigated site. Frequency distributions were calculated for grain yield under the irrigated and nonirrigated environments. Phenotypic correlations among the most promising traits were performed using SAS (1988) procedures.

Recombination: Fall 1991

Plot layout

Two non-replicated blocks, one planted with the full-sibs selected under irrigation and the other with those selected under the rainfed site, were planted on 31 July and 7 August 1991. Stored remnant seed from each of the selected families were hand-planted in two-row plots, 3.6 m long and 0.75 m wide for a density of about 65,000 plants ha^{-1}. Two border rows on each end were planted with Pioneer brand X304C. The blocks were managed for optimum production. Weed control was realized with a mixture of 2.2 kg ha^{-1} Dual [*Metholachlor:2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxyl-methylethyl)acetamide*] and of 3.3 kg ha^{-1} Atrazine, sprayed before seedling emergence and later by hoeing. Insects were controlled with three applications of 2.2 kg ha^{-1} Lannate bait

directly into the whorl of the corn plants. Ammonium nitrate was sidedressed twice at a rate of 45 kg N ha^{-1} after planting. Additional application of fertilizer included 12-4-8 ($N-P_2O_5-K_2O$) at a rate of 224 kg ha^{-1}. Irrigation was provided as needed with overhead sprinklers. The ears resulting from hand pollination were hand-harvested on 20 November 1991, shucked, dried in a forced air dryer to a constant moisture (12%), hand shelled, and bulked accordingly and stored in a seed cold room until used.

Mating scheme

Silks and tassels on plants with similar dates of flowering were covered with bags. Covered tassels were used to pollinate the silks the next day. Reciprocal crosses were made between pairs of plants among the 21 selected families from each of the irrigated and nonirrigated plots. The crosses were identified on the bags in order to facilitate the bulking of the two ears produced by the same parents. The seed derived from each plant involved in a cross were bulked to create full-sib families for future evaluation trials. Approximately two hundred (200) full-sib crosses were obtained for each water treatment.

Evaluation Year 1992

Plant materials

The 1992 irrigated experiment was planted with 194 full-sib families along with two drought-tolerant commercial hybrids (Pioneer brands 3394 and 3165) used as checks. The 194 full-sibs originated from the recombination plots by crossing the 21 superior families, previously selected under irrigated conditions in 1991.

The 1992 rainfed study consisted of 185 full-sib families and eleven checks, of which five were commercial hybrids (Pioneer brands 3394, 3165, 3320, X304C, and DeKalb XL678C), and six were experimental tropical corn populations. The 185 full-sibs originated from the Fall 1991 recombination plots by crossing the 21 superior families, previously selected under rainfed conditions in 1991.

The irrigated test was hand-planted on 17 March 1992 and the rainfed experiment on 18 March 1992. A 14 X 14 partially balanced lattice design was used in both experiments with three (3) replications.

Field management

The two experimental sites were mowed and disked twice before planting. A pre-plant application of 300 kg ha^{-1} of a complete fertilizer (5-10-15) (N-P_2O_5-K_2O) was broadcast over the field site followed by subsoiling and disking. Supplemental fertilization consisted of 90 kg ha^{-1} of KCl, a

split of 650 kg ha^{-1} of $NH_4 NO_3$. Weed control was done through cultivation, hoeing, and application of Atrazine (2.2 kg ha^{-1}). Insects were controlled with Lannate (2.2 kg ha^{-1}) and Furadan 15G at the rate of 11.2 kg ha^{-1}. Irrigation was sprinkler applied as necessary.

Data collected

The same type of variables was measured in 1992 except that no drought susceptibility index was measured due to the fact that different sets of full-sib families were selected from the irrigated and rainfed experiments. Time did not allow for the measuring of total plant dry matter and HI for this year.

Statistical analyses

Statistical analyses were performed for the measured traits using MSTAT 4.01 (1989) for the lattice designs of 1991 and 1992. The full-sib families were separated for all the variables tested using LSD at the 5% level of significance. However, the checks were also included in the analysis of variance with respect to the lattice design used. The superior 21 families were selected (eyeball) based on high grain yield, dry matter yield, plant height, and ear height in the irrigated site. The families were selected based on low canopy temperature, high grain yield, dry matter yield, LAI, LAD, reduced plant and ear height in the nonirrigated site. Specific quantities of remnant seed from each family were bulked to form two experimental synthetics each derived from

the respective water treatment. Seed increase of these experimental materials was performed in the Fall of 1992. Frequency distributions and correlation coefficients were calculated for the most prominent drought-resistant traits related to the two cycles of selection.

Breeding Analyses

Heritability

Heritability values were calculated for both years using variance components from the respective analysis of variance. Genetic variances were estimated by using the expected mean squares (EMS) among the full-sib families. No estimate of genotype x environment interaction was possible since the full-sib families were tested only at a single location and year for both 1991 and 1992. The estimates were then expected to be biased upwards since the genetic component of variance is inflated with the interaction terms (Allard, 1960; Hallauer and Miranda, 1988). The following formula estimates the genetic variance component:

$$\sigma_f^2 = (MS_F - MS_E) / r$$

where:

σ_f^2 = the genetic component of variance

MS_F = the genetic variance due to differences among the full-sib family means

MS_E = variance due to error term, which also expresses the environmental variance

r = number of replications

The values of σ_f^2 and of σ_e^2 were obtained from the analysis of variance table, which had the following shape for one location:

Table 1. Analysis of variance of a randomized complete block design for the estimation of genotypic and phenotypic variances.

SOV†	df	MS	E(MS)	Variance component
Families(F)	f_1	MS_F	$\sigma_e^2 + r\sigma_f^2$	$\sigma_f^2 = (MS_F - MS_E)/r$
Reps.(R)	f_2	MS_R	-	-
Error	$f_1 . f_2$	MS_E	σ_e^2	σ_e^2

† SOV=Source of variation; df=degrees of freedom; MS=Mean squares; E(MS)=Expected mean squares.

Heritability values were then estimated as the ratio of the genotypic variance to the total phenotypic variance.

$$h_{F2} = \sigma_f^2 \ / \ \sigma_P^2$$

where:

$\sigma_P^2 = \sigma_f^2 + (MS_E \ / \ r)$

h_F^2 = heritability for the selected trait.

Confidence limits for the estimates of heritability were calculated as suggested by Knapp et al. (1985). Values from the $F(df_1, df_2)$ distribution were obtained by interpolation as suggested by Laubscher (1965).

Expected genetic gain

The expected genetic gain was calculated as:

$G_s = (k)\ (h^2)$ (adapted from Lush, 1945; Allard, 1960)

where:

G_s represents the expected genetic gain with selection

k is the selection differential (the mean phenotypic value of the selected families minus the population mean

h^2 is the heritability estimated for the selected trait.

Seed Increase

Plot layout

Fall 1992 was used for seed multiplication. Eight non-replicated blocks were established, consisting of rows 6 m long and 0.75 m wide, at a density of about 85,000 plants ha^{-1}. The first six blocks were hand-planted on 13 August 1992 and the last two on 15 August 1992. The entries or blocks were as follows:

1) a bulk of equal amounts of remnant seed of the superior 21 FS families (1987) obtained from crossing four populations, to form Syn 1,

2) a bulk of equal amounts of remnant seed of the 140 full-sibs making the 1991 population, to form Pop 1 (CO),

3) a bulk of equal amounts of remnant seed of the superior 21 full-sib families selected from the 1991 irrigated experiment, to form Syn 2I (C1 for the irrigated site),

4) a bulk of equal amounts of remnant seed of the superior 21 full-sib families selected from the 1991 nonirrigated experiment, to form Syn 2NI (C1 for the nonirrigated site),

5) a bulk of equal amounts of remnant seed of the 194 full-sibs making the 1992 irrigated population, to form Pop 2 (C1 for the irrigated site),

6) a bulk of equal amounts of remnant seed of the 181 full-sibs making the 1992 nonirrigated population, to form Pop 3 (C1 for the nonirrigated site),

7) a bulk of equal amounts of remnant seed of the superior 21 full-sib families selected from the 1992 irrigated experiment, to form Syn 3I (C2 for the irrigated site),

8) a bulk of equal amounts of remnant seed of the superior 21 full-sib families selected from the 1992 nonirrigated experiment, to form Syn 3NI (C2 for the nonirrigated site).

Equal amounts of seed (25 seeds from each full-sib family) was used to make each of the eight entries in the nursery. The nursery blocks were managed for optimum production. A mixture of Dual (2.2 kg ha^{-1}) and of Atrazine (2.2 kg a.i. ha^{-1}) was sprayed for weed control before seedling emergence. The blocks received two split applications of 12-4-8 ($N-P_2O_5-K_2O$), with 420 kg ha^{-1} applied following planting and 392 kg ha^{-1} applied one month later. Furadan 10G (carbofuran) was sprayed at a rate of 2 kg a.i. ha^{-1}

immediately following planting. Three split applications of 2.2 kg ha^{-1} of Lannate bait were made for insect control. Irrigation was provided with overhead sprinklers as needed.

Mating scheme

Silks and tassels on plants with similar dates of flowering were covered with bags. In each block, a bulk of pollen (made of 20 plants at least) from the covered tassels was used to pollinate the silks of other plants the next day.

Seed multiplication was made by hand-pollination in a polycross fashion for each plot to avoid open-pollination. Plants were bagged at flowering time to prevent contamination from the other blocks. Within a block, pollen was mixed, taken from different flowered plants of each row and used to hand-pollinate the mature silks. The multiplication blocks were treated for high yielding conditions. Ears were harvested at physiological maturity on 16 and 17 December 1992, weighed, and dried to a constant moisture (12%), shelled, bulked and stored. The seed derived from the crosses for a block were bulked to create the final synthetics and populations to be included in the final evaluation trials of 1993. An evaluation of progress was determined from these trials after the two cycles of family recurrent selection for drought resistance. Selection progress from the irrigated and nonirrigated treatments was compared.

CHAPTER IV
RESULTS AND DISCUSSION

Experiment 1991

Climatic Conditions

The year of 1991 was characterized by above average rainfall during the corn growing season. Figure 1 shows the normal and total monthly rainfall along with the drought days (days with zero soil water) for the year 1991. The corn growing season was from March to July. Abundant rainfall (88.4 mm) was received at the site compared with the long-term average (normal) rainfall (62.2 mm). In particular, rainfall in March, April, June and July was well above average. Twenty drought-days were obtained as compared with the long-term normal of 63 days during this growing season. Flowering time occurred around May which usually has 18 drought-days, but had only four for this particular corn season. This particular year did not offer the expected drought period for an efficient selection of the full-sib families.

Average maximum air temperatures were near normal for the period March to July 1991 (Figure 2). They ranged from 25^0 C to 33^0 C. The average night temperatures ranged from 11^0 C to 22^0 C.

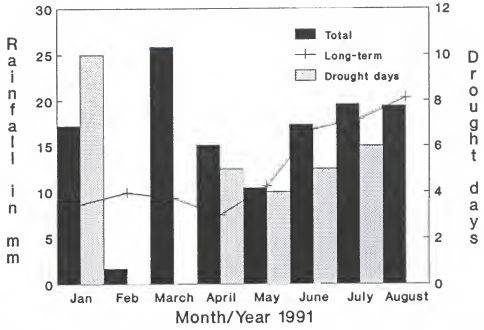

Figure 1. Monthly rainfall for the 1991 corn growing season in Gainesville, FL.

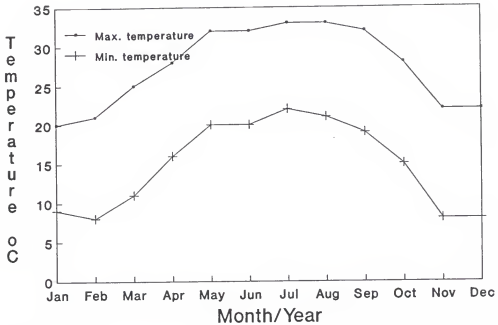

Figure 2. Mean temperatures for the 1991 corn growing season in Gainesville, FL.

ANOVA Results

Grain yield

Highly significant variation ($p<0.001$) existed among the corn materials tested for grain yield (Tables 2 and 3). Although the drought obtained in 1991 was mild, higher grain yields were observed in the irrigated than in the rainfed condition. Grain yield ranged from 6990 kg ha^{-1} to 2637 kg ha^{-1} in the non-irrigated site (Table 4). In the irrigated site, the range was from 8663 kg ha^{-1} to 3906 kg ha^{-1}. The average yields were 6367 kg ha^{-1} and 5090 kg ha^{-1} under irrigated and rainfed regimes, respectively. The rainfed treatment caused marked reductions (12 to 40%) in grain yields both in magnitude and in rank of the full-sib families. Some of the full-sib families yielded more in the non-irrigated than in the irrigated site, probably due to excessive rainfall during the entire growing season resulting in a mild stress, or to a pre-adaptation to stress.

Three of the full-sibs significantly outyielded the highest yielding check (Pioneer brand 3320) in the irrigated environment, whereas none performed better in the stress site. Previous experiments (Gonzalez, 1989; Edme, 1990; Overman, 1991) have shown that in the Spring the temperate hybrid Pioneer brand 3320 usually performs better than or similar to the tropical hybrids or synthetic materials under study. The nonoccurrence of a good period of stress was probably the

Table 2. Analysis of variance (Mean squares) for grain yield, total dry matter, harvest index, plant height, and ear height measured in the irrigated site in 1991.

	Degrees Freedom	Grain Yield	Dry Matter	Harvest Index	Plant Height	Ear Height
Total	575					
Replications	3	2.9×10^6	13.6	0.019	0.22	0.04
Trts (unadj).	143	2.8×10^6**	17.8**	0.030**	0.06**	0.05**
Blocks (within adj.)	44	1.0×10^6	5.3	0.008	0.04	0.024
Intrablock error	385	9.9×10^5	5.9	0.008	0.02	0.012
Effective Error	385	-	-	-	0.02	0.013
Trts (adj).	143	-	-	-	0.06**	0.048**
C.V. (%)		15.7	14.4	20.4	6.40	9.35
Relative efficiency (%)		-	-	-	105	105

*,** Significant at the 0.05 and 0.01 level, respectively.

Table 3. Analysis of variance (Mean squares) for grain yield, total dry matter, harvest index, plant height, and ear height measured in the rainfed site in 1991.

	Degrees Freedom	Grain Yield	Dry Matter	Harvest Index	Plant Height	Ear Height
Total	575					
Replications	3	37×10^6	97.3	0.21	0.66	0.19
Trts (unadj).	143	2.5×10^6**	20.3**	0.021**	0.31**	0.10**
Blocks (within adj.)	44	1.6×10^6	18.8	0.011	0.18	0.40
Intrablock error	385	9.9×10^5	6.7	0.006	1.45	0.02
Effective Error	385	1.0×10^6	7.2	0.006	0.03	0.02
Trts (adj).	143	2.4×10^6**	19.4**	0.021**	0.06**	0.03**
C.V. (%)		19.9	17.3	18.8	14.2	18.2
Relative efficiency (%)		102	111	104	480	318

*,** Significant at the 0.05 and 0.01 level, respectively

main reason for not obtaining a better separation in the stress site. In absolute terms, Pioneer brand 3320 ranked 38th in the good environment and 13th in the rainfed site.

Dry matter production

Highly significant differences ($p<0.001$) existed among the full-sib families for dry matter production from both the rainfed and irrigated sites (Tables 2 and 3). In the irrigated site, 64 of the full-sibs produced significantly more dry matter than the hybrid check (Pioneer brand 3320). In the rainfed site, Pioneer brand 3320 produced less dry matter than 39 full-sibs. Production of dry matter ranged from 23.3 ton ha^{-1} to 11.8 ton ha^{-1} in the irrigated condition, and from 24.5 to 10.9 ton ha^{-1} under the nonirrigated condition (Table 4). A coefficient of variation of 17.3% was observed among the full-sib families in the rainfed site and that of the irrigated experiment was of 14.4%. The effect of water stress on dry matter production depends on what proportion of the total dry matter produced is considered useful for harvest (Fischer and Hagan, 1965). Similar effects of water stress exist on yield and total plant growth when the economic yield is all of the aerial parts of the crop. The effects depend on the stage of growth when the economic yield consists of seeds. The high production of total dry matter produced per unit area is proof of efficient functioning of vital activities of the plants, such as photosynthesis.

Table 4. Statistics on grain yield and total dry matter of the full-sib families (FS) tested under irrigated and rainfed conditions in 1991.

Statistics	Grain Yield		Total Plant Dry Matter	
	Irrigated	Rainfed	Irrigated	Rainfed
	--------kg ha^{-1}-------		------ton ha^{-1}------	
Selected FS†	7668.3	6135.6(20)‡	18.9	17.4
Maximum	8663.2	6990.0	23.3	24.5
Minimum	3906.0	2637.0	11.8	10.9
Population mean	6367.0	5090.0(20)	16.8	15.5
P 3320	6856.8	6053.7(12)	13.6	13.1
LSD (0.05)	1386.8	1409.2	3.4	3.7

† FS = Full-sib families

‡ Numbers in parentheses are differences expressed in percentage of the irrigated yields

The total products depend on the size of the assimilating area, its efficiency, and its duration.

Harvest index

Significant differences ($p<0.001$) were obtained for harvest index (HI) in both the irrigated and rainfed sites (Tables 2 and 3). The irrigated site showed a range of 0.73 to 0.25 with a mean of 0.44 (Table 5). A range of 0.55 to 0.20 with a mean of 0.42 was obtained in the nonirrigated site, that is a reduction of 5% in mean HI. Coefficients of variation (CV) of 20.4% and 18.8% were obtained under the non-irrigated and irrigated experiments, respectively. High HI values were still produced under the suboptimal site indicating that it might be possible and desirable to increase the HI under drought through a decrease in the biological yield. A genotype with less vegetative growth theoretically should be less affected by drought than another with greater vegetative growth.

Plant height and ear height

The corn materials significantly differed ($p<0.001$) for plant height under both the irrigated and nonirrigated plantings (Tables 2 and 3). A CV of 14.2% was observed in the rainfed site and of 6.4% under irrigation. An overall 39% reduction was observed in plant height due to stress. The mean plant heights were 2.2 m and 1.4 m under irrigated

Table 5. Statistics on plant height, ear height, harvest index, and tassel weight of the full-sib families tested under irrigated and rainfed conditions in 1991.

Statistics	PHT†	EHT	HI	Tassel weight
	-------m-------			-----g----
Irrigated				
Selected FS‡	2.30	1.25	0.50	
Maximum	2.46	1.48	0.73	
Minimum	1.90	0.82	0.25	
Population mean	2.22	1.22	0.44	
P 3320 (check)	2.00	0.82	0.73	
LSD (0.05)	0.20	0.16	0.13	
Rainfed				
Selected FS	1.38	0.73	0.46	4.70
Maximum	1.78	1.06	0.55	6.70
Minimum	1.00	0.51	0.20	2.75
Population mean	1.36	0.72	0.42	4.70
P 3320 (check)	1.25	0.51	0.50	2.80
LSD (0.05)	0.27	0.18	0.11	0.90

† PHT = Plant height, HI = Harvest index
EHT = Ear height,
‡ FS = Full-sib families

(ranging from 2.5 m to 1.9 m) and nonirrigated (ranging from 1.8 m to 1.0 m) regimes, respectively (Table 5). The full-sibs grew taller in the better environment.

Reductions in mean heights were due to lower vegetative growth occurring early in the growing season. Abundant rainfall in May and June prevented this reduction in height from decreasing grain yields in some of the full-sib families. Documentation exists on the correlation of the effect of drought and its occurrence on corn yield. Water stress is more detrimental to corn grain yield when it coincides with the flowering and grain filling stages (Downey, 1971; Claasen and Shaw, 1970).

Ear height also showed significant variation ($p<0.001$) among the full-sib families in the irrigated and rainfed sites (Tables 2 and 3). The water stress treatment reduced ear heights by an average of 41%. The mean ear heights were 1.22 m and 0.72 m under irrigated (ranging from 1.46 m to 0.9 m) and nonirrigated (ranging from 1.06 m to 0.52 m) regimes, respectively (Table 5). Field observations during growth of the corn materials suggested that the higher reduction would occur in the lower part of the plant, that is below the ear. Coefficients of variation were 9.40% and 18.20% in the irrigated and nonirrigated conditions, respectively.

Ninety-six full-sibs were significantly taller than the temperate hybrid (Pioneer brand 3320) in the irrigated planting. Tropical corn materials, particularly open-

pollinated, generally show a higher vegetative growth than the temperate counterparts. Only 13 full-sibs were taller than Pioneer brand 3320 in the rainfed site. About 135 full-sibs bore their ears at a higher position on the stalk than the hybrid check in the irrigated environment. In the rainfed site, differences were observed for ear height between the means of Pioneer brand 3320 and those of the full-sibs.

Leaf attributes

LAI measured at flowering. Significant variation ($p<0.001$) existed for LAI measured at flowering among the full-sibs tested, and as compared to the hybrids (Tables 6 and 7). At flowering, LAI ranged from 8.27 to 5.11 in the nonstress field and from 8.22 to 4.69 in the rainfed site (Table 8). The respective LAI means under irrigated and nonirrigated conditions were very similar (6.59 and 6.41). The CV was 14.8% under the nonirrigated planting and 13.8% under the irrigated treatment. Pioneer brand 3320 had an LAI of 5.82 in the irrigated site, and of 4.69 in the stress experiment.

The density used for both experiments (65,000 plants ha^{-1}) might have partly explained these high LAI's obtained under the two water regimes. Leaf area index is the best measure of the capacity of a crop to produce dry matter. Smaller leaf area was reported to contribute to drought tolerance (Dow,

Table 6. Analysis of variance (Mean squares) for leaf attributes measured in the irrigated site in 1991.

	Degrees Freedom	RLI†	LAI†	LAD†
Total	575			
Replications	3	0.001	11.11	8807.53
Trts (unadj).	143	0.001**	1.42**	1368.34**
Blocks (within adj.)	44	0.001	1.10	713.72
Intrablock error	385	0.001	0.81	562.22
Effective Error	385	0.001	0.83	574.46
Trts (adj).	143	0.001**	1.41**	1370.10**
C.V. (%)		6.26	13.81	15.41
Relative efficiency (%)		101	101	101

*,** Significant at the 0.05 and 0.01 level, respectively.
† RLI = Relative leaf initiation LAI = Leaf area index
LAD = Leaf area duration

Table 7. Analysis of variance (Mean squares) for leaf temperature, tassel weight, and leaf attributes measured in the rainfed site in 1991.

	Degrees Freedom	Leaf Temp.	Tassel Weight	RLI†	Leaf area index	Leaf area duration
Total	575					
Replications	3	3.22	3.17	0.002	4.23	2418.3
Trts (unadj.)	143	1.44*	2.70**	0.001**	1.56**	1236.0**
Blocks (within adj.)	44	5.00	0.62	0.001	1.19	696.4
Intrablock error	385	0.68	0.40	0.001	0.88	547.5
Effective Error	385	0.74	0.42	-	0.90	559.5
Trts (adj).	143	0.90*	2.71**	-	1.52**	1214.6**
C.V. (%)		2.63	13.85	4.83	14.8	16.7
Relative efficiency (%)		152	102	-	101	101

*,** Significant at the 0.05 and 0.01 level, respectively
† RLI = Relative leaf initiation

Table 8. Statistics on leaf attributes of the full-sib families tested under irrigated and rainfed conditions in 1991.

Statistics	LAI1†	LAI2	LAD‡	RLI‡	Leaf Temperature
	------m------		days	leaf/day	--^{0}C--
Irrigated					
Selected FS§	6.76	3.88	159.5	0.30	
Maximum	8.31	6.41	219.2	0.33	
Minimum	5.11	0.99	108.6	0.26	
Population mean	6.59	3.78	155.5	0.29	
P 3320 (check)	5.83	3.05	133.2	0.29	
CV (%)	13.82	19.43	15.4	4.83	
LSD (0.05)	1.27	1.01	33.3	0.02	
Rainfed					
Selected FS	6.67	3.04	145.7	0.27	32.40
Maximum	8.22	5.35	198.2	0.30	33.90
Minimum	4.69	1.11	107.9	0.24	31.60
Population mean	6.41	3.07	142.1	0.27	32.60
P 3320 (check)	4.69	2.63	110.0	0.26	32.20
LSD (0.05)	1.32	0.94	32.9	0.02	1.19

† LAI1 = Leaf area index at flowering
LAI2 = Leaf area index at black layer
‡ LAD = Leaf area duration RLI = Relative leaf initiation
§ FS = 21 superior Full-sib families

1981) in a number of hybrids. Variation in total leaf area may result from changes in leaf number or size. However, barrenness and lodging were not problems in these plots as they have been in other experiments (Major and Daynard, 1972).

LAI measured at black layer. There were significant differences ($p<0.001$) among the full-sibs tested for LAI measured at black layer formation in both the nonirrigated and irrigated sites (Tables 6 and 7). The overall mean LAI were 3.78 and 3.07 under irrigated and nonirrigated treatments, respectively (Table 8). An overall reduction of 19% in LAI was obtained due to the water stress, meaning a faster rate of senescence of leaves in the nonirrigated experiment as compared to that in the irrigated site. The check Pioneer brand 3320 showed a decrease of 14%, from 3.05 under irrigated to 2.63 under nonirrigated conditions.

Leaf area duration (LAD). There were significant differences among the full-sib families in both the irrigated and nonirrigated conditions for LAD (Tables 6 and 7). In the irrigated site, LAD ranged from 219 to 109 days, with a mean of 155 days (Table 8). Leaf senescence was faster in the rainfed site. The mean LAD was 142 days under water stress, with a range from 198 to 108 days. The respective coefficients of variation were 15.4% and 16.7% for the irrigated and nonirrigated treatments. An overall reduction of 9% in leaf area duration (LAD) was caused by water stress. Pioneer Brand 3320 was reduced by 17%. Longer duration of the

leaf area would allow for a larger supply of assimilates to the developing ear at grain filling stage.

Relative leaf initiation (RLI). Highly significant differences ($p<0.001$) were observed in both the irrigated and the nonirrigated experiments (Tables 6 and 7). An average of 0.29 leaves day^{-1} and of 0.27 leaves day^{-1} was observed in the irrigated and rainfed environments, respectively (Table 8). Fifteen full-sib families had a significantly faster rate of RLI than Pioneer brand 3320 in the nonirrigated site. Thirteen full-sib families exhibited a significantly faster rate than Pioneer brand 3320 in the irrigated site. No substantial reductions were obtained by not irrigating the rainfed site.

Leaf canopy temperature. Leaf canopy temperature was collected only from the rainfed site and measured at flowering. Significant variation ($p<0.05$) was observed among the full-sib families for this trait (Table 7). The leaf temperatures ranged from 31.6 ^{0}C to 33.9 ^{0}C with a mean of 32.6 ^{0}C (Table 8). Only nine of the 140 full-sibs had a significantly higher leaf temperature than the hybrid check (Pioneer brand 3320) which had 32.2 ^{0}C.

Tassel weight

The full-sib families significantly differed for tassel weight under the rainfed environment (Table 7). The weights ranged from 6.69 g to 2.75 g with an average of 4.67 g

(Table 8). The hybrid check P 3320 had a mean weight of 2.78 g. Most of the full-sib families (124 of them) had significantly heavier tassels than Pioneer brand 3320. Removal of tassel in maize production has the advantage to revert the apical dominance to the developing ears, therefore mobilize more carbohydrates to grain filling, resulting in an increase of grain yield (Hunter et al., 1969). Open-pollinated tropical materials usually produce larger tassels and more vegetative growth than hybrids.

Anthesis-to-silking intervals

The intervals between anthesis and silking ranged from nine days to one day in the non-irrigated site, and from four to two days in the irrigated site. The temperate hybrid Pioneer brand 3320 had a mean delay of four days in both the irrigated and rainfed environments. The drought had increased the intervals between anthesis and silking as compared to the intervals obtained under irrigation. Synchronization of both flower types in maize is critical to maize pollination and subsequent grain yield.

Drought susceptibility indices

Grain yield index. The analysis shows significant differences ($p<0.05$) among the full-sib families for the susceptibility index based on grain yield (Table 9). Most of the full-sibs responded well to the stress treatment. The

range of grain yield indices was from 2.26 to -0.73 (Table 10). Fifty three of the full-sibs had a drought index higher than 1.00, suggesting a relative drought susceptibility. Pioneer brand 3320, however, had a drought index of 0.44, suggesting relative drought tolerance. Its performance in the rainfed site was mainly based on its yield potential in the spring planting, and because its early maturity allowed escape from the drought stress. DeKalb XL678C had a similar drought index score of 0.44. Some full-sib families had both high yield potential and low drought index score. The negative indices resulted from some full-sib families having higher grain yields under the nonirrigated site.

Total dry matter index score. Significant differences were observed for the index score based on total plant dry matter (Table 9). The full-sib families ranged from 2.78 to -1.66 in index score (Table 10). Sixty seven full-sibs had index score higher than 1.00, indicating relative susceptibility to the effects of drought. The temperate hybrid (Pioneer brand 3320) had a drought score of 0.70, which indicates relative tolerance. It might have escaped the drought due to its early maturity. The ranking of the full-sibs in both grain and dry matter scores was similar. The full-sibs with the highest drought index rankings based on grain yield were in general the same for the index based on total plant dry matter.

Table 9. Analysis of variance (Mean squares) for drought susceptibility index based on grain yield and total plant dry matter measured in the rainfed site in 1991.

	Degrees Freedom	GYLD† Index	TDM‡ Index
Total	575		
Replications	3	21.42	17.07
Treatments (unadj.)	143	1.22*	2.66*
Blocks (within adj.)	44	1.22	2.26
Intrablock error	385	1.20	2.31
Effective Error	385		-
Treatments (adj.)	143	-	-
C.V. (%)		25.80	30.02
Relative efficiency (%)		-	-

*,** Significant at the 0.05 and 0.01 level, respectively
† GYLD index = Drought susceptibility index based on grain yield
‡ TDM index = Drought susceptibility index based on total plant dry matter

Table 10. Mean drought susceptibility index for the full-sib families based on irrigated and rainfed conditions in 1991.

	DSI†	
Statistics	Grain Yield	Total Dry Matter
Selected FS‡	0.39	0.44
Maximum	2.26	2.78
Minimum	-0.73	-1.66
Population mean	0.87	0.86
P 3320 (check)	0.44	0.70
LSD (0.05)	1.52	2.11

† DSI = Drought susceptibility index
‡ FS = Full-sib families

Breeding Analyses

Heritability

The heritability estimates for the selected traits are reported in Tables 11 and 12. Generally, higher values for heritability were obtained in the irrigated environment than in the rainfed condition. Values of the genetic components of variance were also larger for the optimal condition. This result was expected since greater genetic variance is usually obtained under optimal conditions, making selection for yield more effective (Daday et al., 1973) than under suboptimal environments.

For grain yield, the heritability estimates were 0.65 and 0.57 from the respective irrigated and rainfed environments. Dry matter yield also had high values of heritability: 0.67 and 0.63 under the irrigated and rainfed conditions, respectively. The heritability estimates for HI were 0.80 under the irrigated site and 0.75 under the rainfed site. The gaps between heritability estimates from both environments were larger for traits like plant height and ear height. Plant height had an heritability value of 0.68 and 0.40 under the respective irrigated and rainfed sites. The heritability estimates for ear height were 0.75 and 0.41 for the nonstress and stress conditions. Heritability estimates for LAI were similar under both environments (h^2 = 0.41).

Table 11. Genetic component of variance, heritability, and expected gain for traits measured in the irrigated site in 1991.

Character	σ_f^2†	h^2†	CI‡	G_g§	G_s§
			LL,UL‡		-%-
Grain yield (kg ha^{-1})	457×10^3	0.65	0.56,0.72	845.85	13.3
Total plant yield (t ha^{-1})	2.980	0.67	0.59,0.74	1.45	8.6
Harvest index	0.006	0.80	0.66,0.78	0.05	11.0
Plant height (m)	0.011	0.68	0.60,0.74	0.054	2.5
Ear height (m)	0.009	0.75	0.67,0.78	0.023	2.0
Leaf area index	0.145	0.41	0.27,0.53	0.07	1.1

† σ_f^2 = Genetic component of variance; h^2 = heritability
‡ CI = Confidence intervals; LL and UL are the lower and upper limits, respectively, of the estimates of heritability (Knapp et al., 1985)
§ G_g = Expected genetic gain in the same unit as the measured trait
G_s = Expected genetic gain in percent of the population mean

Table 12. Genetic component of variance, heritability, and expected gain for traits measured in the rainfed site in 1991.

Character	σ_f^2†	h^2†	CI‡	G_g§	G_s§
			LL,UL‡		-%-
Grain yield (kg ha^{-1})	347×10^3	0.57	0.47,0.66	644.50	12.7
Total plant yield (t ha^{-1})	3.06	0.63	0.54,0.70	1.24	8.0
Harvest index	0.004	0.75	0.62,0.76	0.03	7.0
Plant height (m)	0.006	0.40	0.23,0.50	0.008	0.6
Ear height (m)	0.003	0.41	0.25,0.51	0.004	0.6
Leaf area index	0.155	0.41	0.26,0.53	0.106	1.7
Canopy temperature	0.041	0.18	-0.02,0.34	-0.036	-0.001

† σ_f^2= Genetic component of variance; h^2 = heritability
‡ CI = Confidence intervals; LL and UL are the lower and upper limits, respectively, of the estimates of heritability (Knapp et al., 1985)
§ G_g = Expected genetic gain in the same unit as the measured trait
G_s = Expected genetic gain in percent of the population mean

The heritability values obtained for the measured traits were unusually high, particularly for grain and total plant dry yield, as compared to values obtained by other researchers. Yield in maize and in other crops always has the lowest heritability estimate of all traits measured (Hallauer and Miranda, 1988). It has to be noted that the 1991 evaluation trials for this dissertation research were conducted in only one environment or location and in only one year. Consequently, the interaction terms, genotype x location or genotype x year, were all included in the genetic variance component, which was overestimated as a consequence. This inflated genetic variance resulted in biasing upwards the heritability estimates (Hallauer and Miranda, 1988; Allard, 1960). Estimating such interactions would have the result of lowering the estimates of genetic variance among the family means, the heritability values, and also the expected progress. Moreover, the checks (two of them were hybrids) were also included in the analysis of variance from which the variance components were extracted for estimation of heritability and expected progress.

Expected genetic gain

Values obtained for the expected progress are presented in Tables 11 and 12. Expectations were higher under the irrigated environment than under the rainfed condition. Yield had the highest expectations. Expected progress for grain yield was 13.3% under the irrigated and 12.7% under the

nonirrigated conditions. Selection for total plant dry matter yield resulted in an expected progress of 8.6% and 8% under the irrigated and rainfed sites, respectively. Similar expectations for genetic gain were observed for plant height and ear height under both optimal and suboptimal conditions. Under the irrigated site, expected progress for plant and ear height were 2.5% and 2%, respectively. Under the nonirrigated site, a gain of 0.6% was expected for plant and ear height.

Phenotypic correlations

The coefficients of correlation among the most prominent traits and their significance levels are presented in Tables 13, 14, and 15. The susceptibility index based on grain yield was highly and negatively correlated with grain yield and total plant dry matter under stress, with $r = -0.56$ and $r = -0.37$, respectively (Table 15). Full-sib families with the highest yield potential had the lowest susceptibility index score. Plant height, flower delay, and maturity were not correlated with the susceptibility index. Consequently, this result suggests that the differences among the full-sib families for susceptibility index were not due to escape.

Flower delay was not correlated with yield under stress (Table 14). However, differences in yield under stress correlated with maturity, measured as number of days to silking or to physiological maturity. A low negative correlation ($r = -0.23$) was observed between grain yield and silking or black layer date, whereas a positive correlation

(r = 0.22) was found between total plant dry matter yield and silking or black layer date. The later maturing full-sibs produced more dry matter but at the expense of grain yield in the stress environment. Maturity is a factor to be taken into consideration in this environment. However, grain yield was highly correlated with total plant dry matter with r = 0.46. This suggests that the materials that accumulated more carbohydrates could mobilize a higher percentage to the filling grain under the stress environment.

Differences in plant height and ear height were associated with differences in total plant dry matter (r = 0.34 and r = 0.35), but not in grain yield under stress (Table 14). However, these two plant traits were negatively correlated with HI, with r = -0.19 and r = -0.18, respectively. Shorter full-sibs also had the highest grain yield. Selection for shorter genotypes was reported by Johnson and Fischer (1979) to increase grain yield under optimal environments. Maturity and flower delay were not correlated with plant height.

A negative correlation of -0.18 existed between leaf canopy temperature and grain or total plant yield under stress. The highest yields obtained might be the results of a greater ability to continue photosynthesis under water stress. Among the leaf attributes, only the relative leaf initiation correlated with grain yield under the nonirrigated site (r = 0.24), although differences in LAD, in LAI, and in

Table 13. Phenotypic correlation coefficients for yield and other characters used in selecting families in the irrigated site, 1991.

Trait	1†	2	3	4	5	6	7	8	9	10	11	12	13
	r												
1	1.00												
2	0.64**	1.00											
3	0.49**	0.35**	1.00										
4	-0.03	0.08	0.14	1.00									
5	-0.01	0.14	-0.17*	0.95**	1.00								
6	0.08	0.38**	-0.33**	0.22**	0.20*	1.00							
7	-0.01	0.32**	-0.38**	0.24**	0.24**	0.79**	1.00						
8	0.22**	0.10	0.16	-0.06	-0.02	0.18*	0.14	1.00					
9	0.22**	-0.03	0.28**	0.00	0.01	-0.23**	-0.34**	0.14	1.00				
10	-0.36**	-0.14	-0.29**	0.18*	0.16*	0.22**	0.23**	-0.02	-0.18*	1.00			
11	0.22**	0.09	0.35**	-0.19*	-0.18*	-0.27**	-0.26**	0.07	0.17	-0.92	1.00		
12	0.01	0.26**	-0.29**	0.07	0.13	0.42**	0.54**	0.63*	-0.09	0.12	-0.11	1.00	
13	-0.31**	0.12	-0.51**	0.18*	0.20*	0.18*	0.39**	-0.57**	-0.28**	0.17*	0.24**	0.22**	1.00

*,** Significant at 0.05 and 0.01 levels, respectively

† 1 = Grain Yield; 2 = Total Plant dry matter; 3 = Harvest index; 4 = Plant height; 5 = Ear height; 6 = Leaf area index; 7 = Leaf area duration; 8 = Relative leaf initiation; 9 = Flower delay; 10 = Grain moisture; 11 = Shelling percent; 12 = Leaf number; 13 = Silking date

Table 14. Phenotypic correlation coefficients for yield and other characters used in selecting families in the rainfed site, 1991.

Trait	1†	2	3	4	5	6	7	8	9	10
	r									
1	1.00									
2	0.46**	1.00								
3	0.59**	-0.41**	1.00							
4	0.16	0.34**	-0.19*	1.00						
5	0.16	0.35**	-0.18*	0.83**	1.00					
6	0.10	0.59**	-0.45**	0.28**	0.32**	1.00				
7	0.13	0.47**	-0.27**	0.10	0.16	0.75**	1.00			
8	0.24**	0.14	0.16	0.14	0.20*	0.16	0.21**	1.00		
9	0.08	0.10	-0.28**	-0.08	-0.01	-0.23**	-0.23**	0.34**	1.00	
10	0.01	0.31**	-0.28**	-0.35**	0.38**	0.48**	0.42**	0.70**	0.18*	1.00

*,** Significant at 0.05 and 0.01 level, respectively

† 1 = Grain Yield 2 = Total Plant dry matter 3 = Harvest index
4 = Plant height 5 = Ear height 6 = Leaf area index
7 = Leaf area duration 8 = Relative leaf initiation 9 = Flower delay
10 = Leaf number

Table 15. Phenotypic correlation coefficients for yield and other characters used in selecting families in the rainfed site, 1991.

Trait	1†	2	3	4	5	6	7	8	9	10	11	12	13
	r												
1	1.00												
2	0.46**	1.00											
3	0.59**	0.35**	1.00										
4	-0.23**	0.22**	0.14	1.00									
5	-0.08	0.09	-0.17*	0.18*	1.00								
6	-0.18*	0.20*	-0.33**	-0.09	-0.23**	1.00							
7	-0.08	0.18*	-0.38**	0.06**	0.28**	-0.18*	1.00						
8	0.08	0.10	0.16	-0.47**	-	-	-	1.00					
9	-0.56**	-0.37**	0.28**	0.10	-	-	-	0.10	1.00				
10	0.55**	0.17*	-	-	-	-	-	-	-	1.00			
11	0.47**	0.09	0.55**	-0.23**	-0.07	-0.06	-0.31**	-	-	0.92	1.00		
12	-0.45	0.26**	-0.40**	0.21*	0.00	0.06	0.10	-	-	0.12	-0.11	1.00	
13	0.24**	0.52**	-	-	-	-	-	-	-	0.17*	0.24**	0.22**	1.0

*,** Significant at 0.05 and 0.01 level, respectively

† 1 = Rainfed grain yield 2 = Total Plant dry matter 3 = Harvest index
4 = Silking date 5 = Leaf tissue death 6 = Leaf temperature
7 = Tassel weight 8 = Flower delay 9 = Drought susceptibility index
10 = Irrigated grain yield 11 = Shelling percent 12 = Grain moisture
13 = Irrigated total plant dry matter

leaf number contributed to the differences in total plant yield. Tassel weight was positively correlated with total plant yield (r = 0.32).

In the nonirrigated environment, plant height and ear height did not correlate with grain yield, or with total plant yield (Table 13). The correlations with grain yield tended to be negative, suggesting that shorter plants would provide high grain yield. This was confirmed by their positive correlations with the maturity traits (tasseling, silking, and black layer dates), which were negatively correlated with grain yield (r = -0.33, -0.31, and -0.31, respectively), and also by their negative r-values with HI. Taller families were then the lowest grain producers. Later maturing materials had the lowest grain yield. No correlation existed between maturity traits and total plant yield.

The relative leaf initiation contributed (r = 0.22) to the genetic differences among the full-sib families for grain yield in the irrigated condition. Leaf area index, LAD, and leaf number had larger positive effects on total plant yield than on grain yield. Total plant yield and grain yield were also highly correlated (with r = 0.64), suggesting a higher mobilization of the stored carbohydrates to the developing ear at grain filling stage. Selecting for and improving the HI per se usually results in grain yield improvements in drought affected environments, provided that total dry matter does not decrease.

The families with high yield potential were also found to be the highest yielding families under the nonirrigated condition. Grain yield under the rainfed environment was positively correlated with grain yield ($r = 0.55$) and total plant yield ($r = 0.24$) under the irrigated environment (Table 15 and Figure 3). Total plant yield under the rainfed condition also had a positive correlation with total plant yield ($r = 0.52$) and grain yield ($r = 0.17$) under the irrigated condition (Table 15 and Figure 4). This suggests some possibility of combining high yield potential and drought tolerance in this population.

Despite lower yields, the nonirrigated site in 1991 did not produce an abnormal crop. Correlations of grain yield and other variables were in general similar in the irrigated and nonirrigated environments. These results also suggest that mild moisture stress might not be sufficient for the expression of differences among the full-sib families tested in response to the water stress environments. A better strategy would be to use a site of moderate stress for this initial selection to represent stress conditions to be found in a major part of North Central Florida.

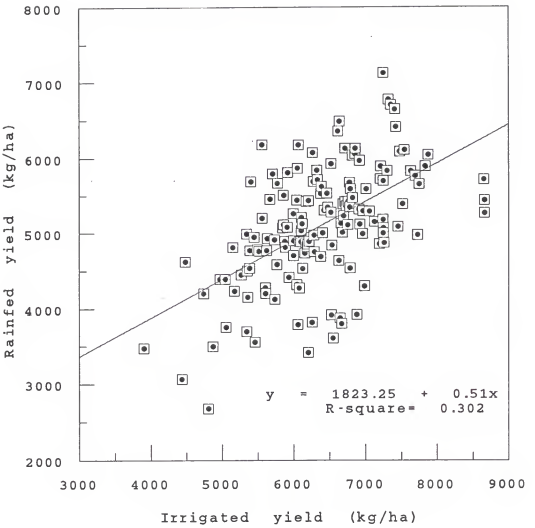

Figure 3. Relationship between grain yield under irrigated and rainfed conditions for the 140 full-sib families tested in 1991.

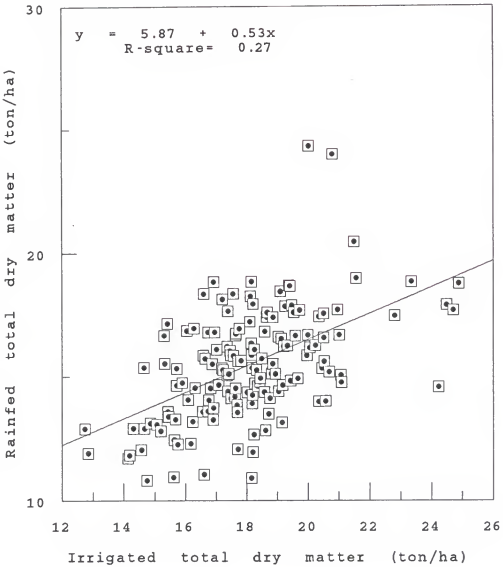

Figure 4. Relationship between total dry matter under irrigated and rainfed conditions for the 140 full-sib families tested in 1991.

Experiment 1992

Climatic Conditions

Figure 5 shows the normal and total monthly rainfall along with the number of drought days (days with zero soil water) for the 1992 corn growing season (March to July). Rainfall was 69.5 mm, slightly above the long-term average, accompanied with 56 drought days of which 23 were in May, the time at which the corn materials flowered. May was particularly dry.

Average maximum air temperatures ranged from 24^0 C to 34^0 C (Figure 6) during the corn growing season. Average night temperatures ranged from 9^0 C to 21^0 C. Higher temperatures were recorded as the season progressed. They peaked in June, which is the normal period of grain filling for the corn materials under study.

ANOVA Results

Grain yield

Highly significant variation ($p<0.001$) was obtained among the full-sib families for grain yield under both rainfed and irrigated experiments (Tables 16 and 17). A CV of 25.85% was observed within the materials under no irrigation while the CV was of 18.1% within the materials under irrigation. Yields ranged from 9917 kg ha^{-1} to 4723 kg ha^{-1} in the irrigated environment (Table 17), and from 6973 to 1663 kg ha^{-1} in the

rainfed site. Mean yields were 7438 kg ha^{-1} and 4250 kg ha^{-1} in the irrigated and rainfed sites, respectively.

In the irrigated experiment, Pioneer brand 3165 ranked 60th with a mean of 8008 kg ha^{-1} and was not significantly different from the top 59 full-sibs. Pioneer brand 3394 ranked 195th with a mean grain yield of 5254 kg ha^{-1}, and performed poorer ($p<0.05$) when compared to Pioneer brand 3165 and 119 of the full-sibs.

In the rainfed site, Pioneer brand 3320 ranked 18th with a mean yield of 5498 kg ha^{-1} and was not significantly different from the top 17 full-sib families. Pioneer brand 3394 ranked 38th with a mean of 4880 kg ha^{-1} which was similar to the yield of the top 28 full-sibs and that of Pioneer brand 3320. Pioneer brand 3165 ranked 144th with a mean of 3613 kg ha^{-1}, which was significantly lower than that of 23 of the full-sibs and of Pioneer brand 3320, but was similar to that of Pioneer brands 3394 and X304C. The difference between the drought-tolerant hybrids, Pioneer brands 3394 and 3165, was 1267 kg ha^{-1}.

Pioneer brand 3394 tended to perform better in the stress experiment, while Pioneer brand 3165 was better in the irrigated site. According to Pioneer Hi-Bred International Pioneer brand 3394 has exceptional drought tolerance and has better root strength than Pioneer brand 3165.

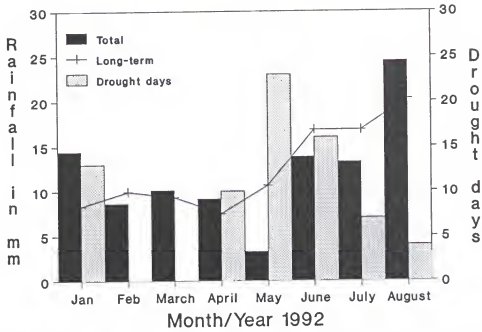

Figure 5. Monthly rainfall for the 1992 corn growing season in Gainesville, FL.

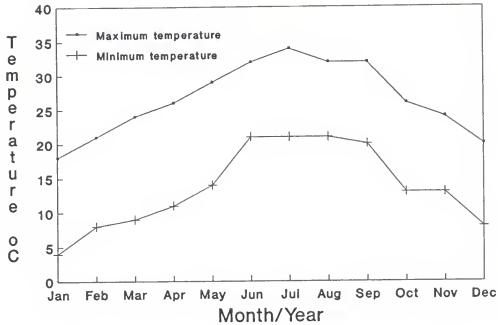

Figure 6. Mean temperatures for the 1992 corn growing season in Gainesville, FL.

Table 16. Analysis of variance (Mean squares) for grain yield, plant height, and ear height measured in the irrigated site in 1992.

	Degrees Freedom	Grain Yield	Plant Height	Ear Height
Total	587			
Replications	2	213×10^6	2.54	2.66
Treatmeant (unadj.)	195	2.98×10^6**	0.06**	0.04**
Blocks (within adj.)	39	3.73×10^6	0.10	0.06
Intrablock error	351	1.13×10^5	0.02	0.012
Effective Error	351	1.21×10^6	0.02	0.013
Treatments (adj.)	195	2.98×10^6	0.05**	0.035**
C.V. (%)		18.1	6.23	10.6
Relative efficiency (%)		115	137	128

*,** Significant at the 0.05 and 0.01 level, respectively

Table 17. Analysis of variance (Mean squares) for grain yield, plant height, and ear height measured in the rainfed site in 1992.

	Degrees Freedom	Grain Yield	Plant Height	Ear Height
Total	587			
Replications	2	37×10^{6}	2.40	2.92
Treatments (unadj.)	195	3.4×10^{6}**	0.05**	0.033**
Blocks (within adj.)	39	2.7×10^{6}	0.07	0.055
Intrablock error	351	1.8×10^{5}	0.01	0.014
Effective Error	351	1.8×10^{6}	0.02	0.015
Treatments (adj.)	195	3.4×10^{6}**	0.05**	0.030**
C.V. (%)		25.85	7.21	15.03
Relative efficiency (%)		115	127	121

*,** Significant at the 0.05 and 0.01 level, respectively

Table 18. Mean yield, plant height, and ear height performance of the full-sib families tested under irrigated and rainfed conditions in 1992.

Statistics	Grain Yield		PHT†		EHT†	
	IRR‡	NIR	IRR	NIR	IRR	NIR
	------kg ha^{-1}------		-----m-----		-----m-----	
Selected fullsibs	8954.80	5616.85(37)§	2.24	1.74	1.15	0.85
Maximum	9917.15	6973.27	2.52	2.01	1.36	1.08
Minimum	4722.80	1662.62	1.74	1.24	0.73	0.45
Population mean	7438.08	4250.10(43)	2.15	1.71	1.09	0.81
Checks						
P 3394	5253.70	4880.13(7)	1.74	1.24	0.73	0.52
P 3165	8007.93	3613.32(55)	1.91	1.43	0.83	0.51
LSD (0.05)	2160.06	1764.12	0.20	0.18	0.19	1.04

† PHT= Plant height EHT= Ear height
‡ IRR= Irrigated NIR= Non irrigated
§ Numbers in parentheses are differences expressed in percentage of the irrigated yields

Plant and ear height

Plant height differences were highly significant ($p<0.01$) in both the irrigated and nonirrigated experiments (Tables 16 and 17). Plant height ranged from 2.52 m to 1.74 m in the irrigated site (Table 18). Pioneer brand 3394 (with a mean height of 1.74 m) and Pioneer brand 3165 (with a mean height of 1.91 m) were among the shortest cultivars, ranking 196th and 191st, respectively. Most of the tropical materials (113 full-sib families) were taller than Pioneer brands 3394 and 3165.

A range in plant height from 2.01 m to 1.24 m was observed in the rainfed site (Table 18). Both Pioneer brands 3165 and 3394 grew the shortest with respective means of 1.43 m and 1.24 m, and respective ranks of 193rd and 196th. Pioneer brand 3320 was also short with a mean height of 1.46 m.

Ear height was more variable than plant height in both the irrigated and rainfed experiments. Coefficients of variation were 10.6% and 15.0% for the irrigated and rainfed sites (Tables 15 and 16). Ear heights ranged from 1.36 m to 0.73 m under no stress, and from 1.07 m to 0.45 m under stress (Table 17). The drought tolerant checks Pioneer brands 3394 and 3165 were the shortest when compared with the full-sibs, with respective means of 0.73 m and 0.83 m in the irrigated conditions. In the rainfed experiment, Pioneer brand 3165 had

a reduction in ear height of 45%, whereas Pioneer brand 3394 exhibited a reduction in ear height of 29%.

Leaf attributes

LAI measured at flowering. Highly significant differences ($p<0.001$) were observed for LAI measured at flowering among the full-sibs tested in both the rainfed and irrigated environments (Tables 19 and 20). Higher LAI were obtained in the irrigated than in the rainfed site (Table 21). Leaf area indices ranged from 7.28 to 2.49 in the irrigated environment corresponding to a mean of 4.72. Under rainfed conditions, LAI ranged from 5.6 to 2.48 with an average of 4.07. A coefficient of variation of 15.4% was observed under the stress condition as compared to 13.7% under the irrigated condition.

The hybrids, Pioneer brands 3165 and 3394, ranked 125th and the least, with respective LAI means of 4.44 and 2.49 in the irrigated site. Twenty four of full-sibs had higher LAI than Pioneer brand 3165 at flowering, whereas 190 out of 194 the full-sibs developed higher LAI than Pioneer brand 3394 in the irrigated site.

Under the rainfed regime, Pioneer brand 3394 still had the lowest LAI with a mean of 2.48. Pioneer brand 3165 ranked 165th with a mean of 3.51 which was significantly smaller than that of 36 of the full-sib families. Pioneer brand 3320

Table 19. Analysis of variance (Mean squares) for leaf attributes measured in the irrigated site in 1992.

	Degrees Freedom	RLI†	LAI1‡	LAI2	LAD†
Total	587				
Replications	2	0.001	24.30	4.03	6121.4
Treatments (unadj.)	195	0.001**	2.10**	2.15	1715.9**
Blocks (within adj.)	39	0.001	3.80	2.11	4016.9
Intrablock error	351	0.001	0.38	0.17	301.9
Effective Error	351	0.001	1.54	1.85	1465.2
Treatments (adj.)	195	0.001**	0.42**	0.19	329.8**
C.V. (%)		2.05	13.70	20.30	16.90
Relative efficiency (%)		102	174	196	204

*,** Significant at the 0.05 and 0.01 level, respectively
† RLI = Rlative leaf initiation LAD = Leaf area duration
‡ Leaf area index-1 = LAI measured at flowering
Leaf area index-2 = LAI measured at black layer formation

Table 20. Analysis of variance (Mean squares) for leaf attributes measured in the rainfed site in 1992.

	Degrees Freedom	RLI†	Leaf Temp.	LAI1	LAI2	Leaf Area Duration
Total	587					
Replications	2	0.007	592.90	45.80	19.62	28083.4
Treatments (unadj.)	195	0.001**	4.12*	0.97**	1.16**	743.3**
Blocks (within adj.)	39	0.001	7.04	1.00	0.38	560.4
Intrablock error	351	0.001	3.30	0.37	0.18	226.7
Effective Error	351	0.001	3.50	0.39	0.19	240.2
Treatments (adj.)	195	0.001**	4.03*	0.92**	0.16	736.1**
C.V. (%)		5.91	5.35	15.42	22.08	17.05
Relative efficiency (%)		101	106	110	105	108

*,** Significant at the 0.05 and 0.01 levels, respectively
† RLI = Rlative leaf initiation LAD = Leaf area duration
‡ Leaf area index-1 = LAI measured at flowering
Leaf area index-2 = LAI measured at black layer formation

Table 21. Statistics on leaf area index of the full-sib families tested under irrigated and rainfed conditions in 1992.

Statistics	LAI1†		LAI2†	
	IRR‡	NIR	IRR	NIR
Selected FS§	5.25	4.40	2.22	2.03
Maximum	7.28	5.60	4.95	4.09
Minimum	2.49	2.48	0.27	0.65
Population mean	4.72	4.07	2.13	1.99
Checks				
P 3394	2.49	2.48	0.27	0.65
P 3165	4.44	3.51	1.22	1.32
LSD (0.05)	1.04	1.01	0.69	0.70

† LAI1 = Leaf area index at flowering
LAI2 = Leaf area index at black layer
‡ IRR = Irrigated NIR= Non irrigated
§ FS = Full-sib families

ranked 184th with a mean of 3.21, and had significantly lower ($p<0.05$) LAI than 72 of the full-sibs.

LAI measured at black layer. The corn materials tested significantly different ($p<0.001$) for LAI measured at black layer formation in both the rainfed and irrigated environments (Tables 19 and 20). The irrigated site had an overall mean LAI of 2.13 and a range of 4.95 to 0.27 (Table 21). Pioneer brand 3394 maintained the lowest LAI at black layer formation with a mean of 0.27. Pioneer brand 3165 had a higher LAI with a mean of 1.22, and ranked 175th among the materials. In general, the tropical full-sibs kept higher LAI at black layer than the two hybrids in the irrigated site.

In the non-irrigated site, Pioneer brand 3394 still occupied the last ranking with a mean of 0.65. Pioneer brand 3165 had a mean LAI of 1.32, ranking 173rd, whereas Pioneer brand 3320 ranked 145th with a mean of 1.56, significantly higher than that of Pioneer brand 3394. Most of the full-sibs maintained their LAI at black layer formation better than their hybrid counterparts. This might indicate good potential among the full-sib materials for high production.

Leaf area duration (LAD). Highly significant variation ($p<0.001$) existed for LAD among the corn materials under both irrigated and rainfed conditions (Tables 19 and 20). A higher overall mean (107.5 days) was found under the irrigated environment than under the rainfed site (91 days) (Table 22).

Table 22. Mean leaf area duration, relative leaf initiation, and leaf canopy temperature of the full-sib families tested under irrigated and rainfed conditions in 1992.

Statistics	LAD†		RLI†		Leaf Temperature
	IRR‡	NIR‡	IRR	NIR	NIR
	------days-----		--leaf day^{-1}--		--^{0}C--
Selected FS§	111.90	96.30	0.21	0.23	34.08
Maximum	187.60	141.08	0.26	0.26	38.60
Minimum	50.00	52.00	0.13	0.17	32.00
Population mean	107.50	90.90	0.20	0.21	34.80
Checks					
P 3165	89.03	72.60	0.18	0.20	34.60
P 3394	50.00	50.00	0.13	0.17	34.50
LSD (0.05)	29.20	24.90	0.01	0.02	3.00

† LAD= Leaf Area Duration RLI= Relative leaf initiation
‡ IRR= Irrigated NIR=Nonirrigated
§ FS = Full-sib families

The corn materials maintained their leaf areas longer when irrigated than when non-irrigated. The range of LAD was from 50 days (Pioneer brand 3394) to 187.6 days in the irrigated site, and from 52 to 141 days in the nonirrigated site. Water stress hastened leaf senescence as opposed to no water stress. The drought-tolerant hybrid Pioneer brand 3394 was about the same in both the rainfed and irrigated environments, maybe because it is also earlier than the other tropical materials. Pioneer brand 3165, the other drought resistant hybrid, had a reduction of 18.7% in LAD due to water stress. In the rainfed site, Pioneer brands 3165, 3320, and P 3394 had similar LAD, which was lower than that of Pioneer brand X304C (105 days).

Leaf canopy temperature. Significant variation ($p<0.05$) was observed for canopy temperature at flowering among the materials tested under rainfed conditions (Table 20). However, cloudy and windy days at the time of measurement prevented a good separation among the full-sib families. The overall mean temperature was 34.8^0 C (Table 22). Other researchers have pointed out the inconsistency and limitations of leaf canopy temperature as a means of separating genotypes under non-irrigated environments. Some degree of drought stress is required to result in differences among genotypes (Blum et al., 1982; Harris et al., 1984).

Relative leaf initiation. Significant variation was obtained for RLI among the full-sibs tested (Tables 19 and

20). The irrigated site initiated leaf at a mean rate of 0.20 leaves day^{-1} while the rainfed site exhibited a mean rate of 0.22 leaves day^{-1} (Table 22). This suggests a slightly faster overall rate of growth in the rainfed condition. The range was from 0.26 to 0.13 leaves day^{-1} in the irrigated site and from 0.26 to 0.17 leaves day^{-1} in the non-irrigated experiment. Pioneer brand 3394 initiated leaves at a rate of 0.13 leaves day^{-1}, which was significantly slower than that of the full-sibs and of Pioneer brand 3165. Pioneer brand 3165 had a mean rate of 0.18 leaves day^{-1}. The full-sib materials initiated leaves at a significantly faster rate than the two drought-tolerant hybrids (Pioneer brands 3394 and 3165) in the irrigated environment. In the rainfed environment, Pioneer brand 3165 (0.20), Pioneer brand X304C (0.20), Pioneer brand 3320 (0.19), and Pioneer brand 3394 (0.17) were not different from each other. The tropical full-sib materials initiated leaves at a significantly faster rate in the nonirrigated environment than the hybrids.

Anthesis-to-silking intervals. The materials reached physiological maturity at an earlier date in the rainfed treatment than in the irrigated treatment. Mean black layer date was 113.5 days after planting (DAP) in the irrigated environment and 116 days DAP in the rainfed treatment. Tasseling date was two days earlier in the rainfed environment. The irrigated and rainfed sites had a similar

overall mean delay of six days. However, drought tended to increase the number of days to tasseling and to silking. The irrigated site had respective mean tasseling and silking dates of 78 and 84 days DAP, whereas the rainfed site had mean tasseling and silking dates of 80 and 86 days, respectively. Physiological maturity was reached at 114 days DAP under the irrigated condition and at 116 days DAP under the rainfed site.

Breeding Analyses

Heritability

Tables 23 and 24 show the heritability values obtained for the traits under selection. Similarly to 1991, heritability for grain yield was higher in the irrigated (h^2 = 0.59) than in the rainfed treatment (h^2 = 0.47). The other traits also exhibited higher heritability values under the irrigated than under the rainfed environment. Heritability estimates were 0.66 and 0.67 for plant height, 0.62 and 0.50 for ear height, 0.74 and 0.57 for LAI, 0.77 and 0.67 for leaf area duration, under the irrigated and rainfed sites, respectively. Leaf canopy temperature had the lowest h^2 value, estimated at 0.14 in the rainfed environment. Generally, higher values for heritability were obtained in the irrigated than in the rainfed environment for most traits.

Table 23. Genetic component of variance, heritability, and expected gain for traits measured in the irrigated site in 1992.

Characters	σ_f^2†	h^2†	CI‡	G_g§	G_g§
			LL,UL‡		-%-
Grain yield (kg ha^{-1})	590×10^3	0.59	0.34,0.56	806.38	19.0
Plant height (m)	0.012	0.66	0.59,0.73	0.06	2.8
Ear height (m)	0.007	0.62	0.53,0.69	0.04	3.4
Leaf area index	0.38	0.74	0.67,0.78	0.11	2.4
Leaf area duration (days)	378.45	0.77	0.72,0.82	3.42	3.2
Leaf initiation (days)	1.00	1.00	0.98,0.99	0.01	5.0

† σ_f^2 = Genetic component of variance; h^2 = heritability
‡ CI = Confidence intervals; LL and UL are the lower and upper limits, respectively, of the estimates of heritability (Knapp et al., 1985)
§ G_g = Expected genetic gain in the same unit as the measured trait
G_s = Expected genetic gain in percent of the population mean

Table 24. Genetic component of variance, heritability, and expected gain for traits measured in the rainfed site in 1992.

Characters	σ_f^2†	h^2†	CI‡	G_g§	G_s§
			LL,UL‡		-%-
Grain yield (kg ha^{-1})	528×10^3	0.47	0.50,0.67	697.70	9.4
Plant height (m)	0.01	0.67	0.58,0.72	0.02	1.2
Ear height (m)	0.005	0.50	0.40,0.60	0.02	2.5
Leaf area index	0.174	0.57	0.47,0.65	0.19	4.6
Leaf area duration (days)	165.30	0.67	0.60,0.73	3.66	4.0
Leaf initiation (days)	1.00	1.00	0.79,0.86	0.01	4.6
Temperature (^{0}C)	0.19	0.14	0.06,0.30	0.105	-0.3

† σ_f^2 = Genetic component of variance; h^2 = heritability
‡ CI = Confidence intervals; LL and UL are the lower and upper limits, respectively, of the estimates of heritability (Knapp et al., 1985)
§ G_g = Expected genetic gain in the same unit as the measured trait
G_s = Expected genetic gain in percent of the population mean

The heritability values obtained for the measured traits were inflated, as in 1991 and particularly for grain yield. However, they indicate the relative degree to which the genotypic values of the selected individuals are expected to be transmitted to their offspring through selection. Using only one location in 1992 also inflated the genetic variance component as in 1991. The variability among the full-sib families was maintained in 1992 and was higher in either environment than in 1991. There is still room for improvement of the two divergent populations under selection.

Expected genetic gain

Values obtained for the expected progress are presented in Tables 23 and 24. Expectations were higher under the irrigated than under the rainfed environment, except for grain yield and LAI. The highest expected gains were observed for grain yield in the irrigated (19%) and in the rainfed sites (9.4%). The expected genetic gains were larger for the traits measured in 1992 than in 1991.

Phenotypic correlations

In the rainfed environment, taller full-sib families tended to have high grain yield. Correlation between grain yield and plant height and ear height were 0.24 and 0.29, respectively (Table 25). This suggests that the full-sibs with a good vegetative growth maintained the ability to carry on a normal activity under the stress site. Several

Table 25. Phenotypic correlation coefficients for grain yield and other characters used in selecting families in the rainfed site, 1992.

Trait	1†	2	3	4	5	6	7	8	9	10	11	12	13	14
	r													
1	1.00													
2	0.24**	1.00												
3	0.29**	0.78**	1.00											
4	-0.44**	0.24**	0.26**	1.00										
5	-0.63**	-0.10	-0.17*	0.42**	1.00									
6	0.14*	0.45**	0.39**	0.03	0.06**	1.00								
7	-0.14**	0.19**	0.12	0.10	0.30**	0.16*	1.00							
8	0.63**	-0.17*	-0.05	-0.12	-0.39**	-0.06	-0.14	1.00						
9	-0.26**	0.25**	0.15*	-0.00	0.25**	0.13	0.14	-0.58**	1.00					
10	-0.30**	-0.03	-0.16*	0.13	0.19**	0.01	-0.03	-0.34**	-0.29*	1.00				
11	0.28**	0.52**	0.51**	-0.23**	-0.21**	0.66**	0.04	-0.13	0.19*	-0.01	1.00			
12	0.27**	0.35**	0.38**	-0.03	-0.06	0.80**	0.10	-0.15*	-0.05	-0.51*	0.51*	1.00		
13	0.07	0.24**	0.18*	-0.09	-0.04	0.52**	-0.02	-0.18**	0.34*	0.26*	0.56*	0.28*	1.00	
14	0.19**	0.42**	0.38**	-0.17*	-0.14*	0.66**	0.01	-0.18*	0.30*	0.15*	0.87*	0.44*	0.89*	1.

*,** Significant at 0.05 and 0.01 level, respectively

† 1 = Grain Yield 2 = Plant height 3 = Ear height
4 = Leaf temperature 5 = Leaf rolling 6 = Leaf Number
7 = leaf tissue death 8 = Shelling percent 9 = Grain moisture
10 = Silking date 11 = leaf area index at flowering
12 = Relative leaf initiation 13 = Leaf area index at black layer
14 = leaf area duration

Table 26. Phenotypic correlation coefficients for grain yield and other characters used in selecting families in the irrigated site, 1992.

Trait	1†	2	3	4	5	6	7	8	9	10	11
	r										
1	1.00										
2	0.40**	1.00									
3	0.45**	0.83*	1.00								
4	0.27**	0.50**	0.49**	1.00							
5	0.14**	0.28**	0.25**	0.28**	1.00						
6	0.18*	0.34**	0.34**	0.42**	0.95**	1.00					
7	0.23**	0.34**	0.34**	0.59**	0.42**	0.45**	1.00				
8	0.06**	0.02	0.04	0.32	-0.62**	-0.43**	0.26**	1.00			
9	0.22**	0.35**	0.33**	0.68**	0.46**	0.49**	0.93**	0.29**	1.00		
10	-0.10	-0.04	-0.08	0.05	0.01	0.03	-0.37**	-0.02	-0.09	1.00	
11	0.19**	0.25**	0.13	0.18**	0.12	0.13	0.01	-0.13	0.05	0.08	1.00

*,** Significant at 0.05 and 0.01 level, respectively

† 1 = Grain Yield
2 = Plant height
3 = Ear height
4 = Leaf area index at flowering
5 = Leaf area index at black layer
6 = leaf area duration
7 = Relative leaf initiation
8 = leaf tissue death
9 = Leaf number
10 = Silking date
11 = Grain moisture
13 = leaf area index at black layer
14 = leaf area duration

researchers reported a significant positive correlation between grain yield and either ear height (Josephson and Kincer, 1974; Acosta and Crane, 1972) or plant height (Moll and Kamprath, 1977). These correlations are usually affected by plot size, plant density, and harvest area.

Leaf canopy temperature and leaf rolling were negatively correlated with grain yield, with respective r-values of -0.63 and -0.44. The highest yielding families would have a normal transpiration with the effect of cooling the leaves under this environment. Leaf tissue death was negatively correlated ($r = -0.14$) and LAD was positively correlated ($r = 0.20$) with grain yield. The distribution of assimilates during grain filling, which is important for performance under this environment, might have played a determining role. This was also confirmed by the positive correlations of LAI measured at flowering ($r = 0.28$) and of leaf number ($r = 0.14$) with grain yield.

The maturity trait (days to silk) explained the genetic differences among the families for grain yield with a similar correlation of -0.30. Earlier maturing families would be better performers under the drought conditions of 1992. The observed differences might have been due to escape mechanisms.

The differences in grain yield among the families were not explained by maturity under the irrigated site (Table 25). No correlation was found. However, the vegetative traits such as LAI measured at flowering, plant height, ear height, leaf

number, LAD, and RLI were all positively correlated with grain yield. Irrigation removed the effects of maturity and leaf tissue death upon yield since both traits were not important in this environment.

Frequency distribution

The frequency distribution plots for grain yield are presented in Figures 7 and 8 for the irrigated and the rainfed selections, respectively. There was not a true drought occurring in 1991 as there was in 1992 and the other attributes included in the selection under the rainfed site might not have been really the resulting effects due to drought. Different sets of full-sib families were included in the 1992 irrigated and nonirrigated experiments. The frequencies fell into a symmetrical unimodal distribution and may be assumed to indicate polygenic control of the trait.

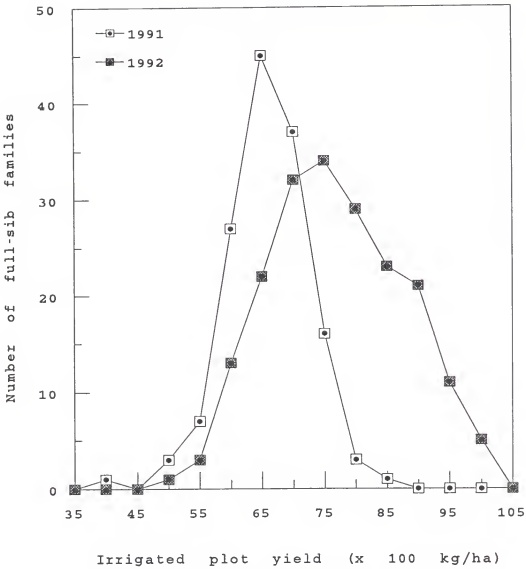

Figure 7. Frequency distribution for grain yield under the 1991 and 1992 irrigation studies.

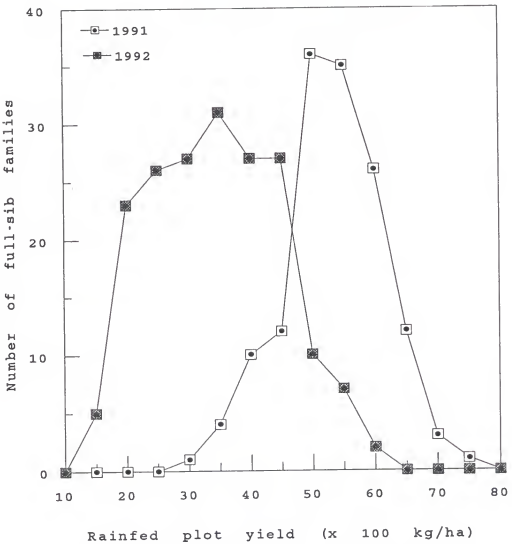

Figure 8. Frequency distribution for grain yield under the 1991 and 1992 rainfed studies.

CHAPTER V
RESPONSE TO SELECTION FOR DROUGHT TOLERANCE IN TWO POPULATIONS EVALUATED IN DIFFERENT ENVIRONMENTS

Introduction

Grain yield is the most important economic trait in corn breeding. Drought is one of the most important constraints to maize (*Zea mays* L.) yield, particularly in the tropics as well as in much of the temperate zones. An enhanced effort has been developed towards breeding for drought tolerance or resistance within different crops. The techniques of genetic engineering used together with the conventional techniques may help in increasing the productivity of corn under these low-yielding environments.

Full-Sib Family Selection and Genetic Gain

Sophisticated methods had been developed for the improvement of corn, with more or less emphasis on the maintenance of genetic variability through generations. The presence of genetic variance is essential to achieve progress from selection. Recurrent selection methods had been used with success to develop and improve genetically broad-based populations, particularly in tropical areas (Hallauer and Miranda, 1988; Sprague and Eberhart, 1977).

Recurrent selection methods, in general, had been effective in improving various agronomic traits (Hallauer et al., 1983; Horner et al., 1989) and response to selection was obtained in most instances. Generally gains of 2 to 4% per cycle were obtained for yield regardless of the genetic background (Hallauer and Miranda, 1988). One of the advantages of these methods is the development of improved populations as potential sources of inbred lines for hybrid breeding. Horner et al. (1973) used a released commercial maize seed parent as tester to develop commercial hybrids from a recurrent selection program.

Profuse documentation exists on the success of full-sib (FS) family selection, in particular, in improving corn yields (Moll and Hanson, 1984; Compton and Lonnquist, 1982). Reduction in traits such as plant height, ear height, lodging, and number of days to maturity has been achieved. In some instances, FS family selection was found to be more effective than 1) half-sib family selection for traits of low heritability (Hallauer and Miranda, 1988), 2) other selection methods in instances of dissimilar seasons year^{-1} and no dominance variance (Hallauer and Miranda, 1988) and 3) mass selection (Hallauer and Miranda, 1988; Sanghi, 1983).

Moll and Hanson (1984) found that 10 cycles of FS family selection for grain yield led to a 2.62% gain cycle^{-1} for Jarvis and 0.65% cycle^{-1} for Indian Chief populations. Numbers of ears increased also in conjunction with grain yield. It

seems that these gains cycle^{-1} depended on the initial levels of yield in these two populations. Different rates of response were also observed in a study with eight tropical populations by Pandey et al. (1986), and the rates were associated with the initial yield levels in these populations. Average gains cycle^{-1} across populations showed an increase in grain yield (1.31%) and ears plant^{-1} (0.87%) and decreases in days to silk (0.59%), plant height (1.06%), ear height (1.77%), and ear rating (1.15%).

Fifteen cycles of FS family selection increased the harvest index in the Tuxpeno Crema 1 population from 0.30 to 0.45 with a positively correlated increase in grain yield (2.1% cycle^{-1}; 4.4% cycle^{-1} at the optimum plant density) and kernel numbers, and a negatively correlated decrease in plant height (2.4% cycle^{-1}) and total dry matter (Johnson et al., 1986). Progress from selection varies with the selection intensity and heritability of the trait. Full-sib family selection was also effective in improving the performance of population crosses (Moll and Hanson, 1984).

Genotype-Environment Interaction

Adaptation is a state of fitness of a given genotype or population to a given environment (Simmonds, 1962). The determination of genotype x environment (GE) interaction is important to breeders in order to separate the genotypic from the environmental effects. Breeders are interested in knowing

if certain varieties perform well over a wide range of environments and if others are good in a specific environment. Assessing the components that confer wide or specific adaptation to varieties is essential to breeders in the identification of genotypes with varying levels of adaptation. In order to identify superior genotypes, the breeder evaluates his materials over a number of locations or seasons and/or years. The interaction between plant traits related to adaptability and the prevailing range of environmental conditions are also to be recognized in the process.

Synthetic varieties are heterogeneous populations which have a greater capacity to stabilize productivity over a range of varying environments (Allard, 1960; Simmonds, 1981). The heterogeneity feature itself confers a higher degree of population buffering, called homeostasis (Frey, 1987). Heterozygous populations are also said to have a better buffering ability than homozygous materials.

Stability Analysis

Breeders aim at surpassing the adaptive level of existing varieties. However, for subsistence farmers, stability of production may be more important than high yields. Different procedures had been proposed to measure yield stability over a range of environments. Experimental data can be used to categorize the environments of the test sites (Horner and Frey, 1957). Rank correlations (Gotoh and Fujimori, 1960) or

cluster analysis (Abou-El-Fittouh et al., 1969) were also useful in categorizing the areas of adaptation of experimental varieties.

Yates and Cochran (1938) suggested a biological model to obtain a general idea of environmental response and varietal adaptation. This assessment can be made by regressing the individual varietal performance on varietal means over environments. This technique was further developed by Finlay and Wilkinson (1963) and is now widely used to quantify the adaptation of a number of cultivars on the basis of multilocation testing.

Moll et al. (1978) reported, from an investigation on corn yield, that this regression depends 1) on the actual magnitude of the responses to the environments and 2) on the correlations of the responses of the individual varieties between environments. As for any regression, over-interpretation of the results should not be made. Knight (1970, 1973) noted that the interactions are forced into a linear form which, in many cases, may be inappropriate. Response to an environmental agent is usually curvilinear. Eberhart and Russell (1966) used the general method of taking the environmental index as the mean performance of all genotypes tested in an environment. Besides the regression coefficient (b), they used the mean square deviation from regression (s^2_d) to define a stable variety as one with $b = 1.0$ and $s^2_d = 0$. In Mather and Caligari (1974) the environmental

index is the mean of all other genotypes minus that of the corresponding genotype.

Yield stability is under genetic control (Scott, 1967). Effective selection for yield stability (Tsai et al., 1970) can be carried out in two contrasting environments (locations or seasons) and this method was called 'disruptive seasonal selection' by Oka (1967). Most of the stability analyses were carried out for yield to classify varieties as stable, intermediate, or highly responsive to environmental improvement. Stability may be equally important for characters such as flowering time, maturity, grain size, and grain filling, which are all yield components (Gotoh and Chang, 1979).

The objectives of our study were to: 1) to measure the response to selection for drought resistance, using two experimental maize synthetics developed through FS family selection, respectively under irrigated and nonirrigated conditions; 2) to determine the yield stability of a set of populations over three planting dates and two water regimes; 3) to determine the interaction between plant traits associated with adaptability.

Materials and Methods

Seven trials were conducted in 1993 following a full-sib recurrent selection for drought tolerance in tropical corn. Six of the trials were carried out at the Green Acres Agronomy

farm, of the University of Florida, Gainesville, FL, and the other one on the Gallahers' farm, Waynesboro, TN. The Florida soil was classified as an Arredondo fine sand (sandy, siliceous, thermic, Grossarenic Paleudult with 94% sand, 2% silt, and 4% clay) (Soil survey Staff, 1984), and the Tennessee soil as an Ennis cherty loam (fine-loamy siliceous thermic Fluventic Dystrochrept with 46% sand, 34% silt, and 20% clay).

Plant Materials

Twelve corn genotypes were included in the 1993 evaluation trials. They were: two final experimental synthetics representing C2 for the respective irrigated and nonirrigated conditions, four synthetics representing C1 for the respective irrigated and nonirrigated conditions, four commercial hybrids from Pioneer Hi-Bred Seed Company, and four other populations (Table 27). The first eight populations listed resulted from hand-pollinating in a polycross fashion for seed increase in the Fall of 1992.

Field Management

The 12 genotypes were planted at three different dates at Gainesville, FL in 1993 and under irrigated and rainfed treatments for each date. The planting dates were on March 19, May 17, and July 13, for the irrigated site. The rainfed treatments were planted on March 18, May 18, and July 13. The

Table 27. Identification of the entries for the 1993 planting date study at Green Acres experiment farm, Gainesville, FL.

Name	Origin
Syn 1	Superior 21 full-sibs from crosses of 4 populations
Pop. 1	Representing CO, made from bulking and hand-pollinating (by polycross) remnant seed of the 1991 population of 140 full-sibs
Syn 2I†	Representing $C1_I$ for the irrigated site, made from bulking and hand-pollinating (by polycross) remnant seed of the 21 superior full-sibs selected in 1991
Syn 2NI‡	Representing $C1_{NI}$ for the nonirrigated site, made by bulking and hand-pollinating (by polycross) remnant seed of the 21 superior full-sibs selected in 1991
Pop. 2	Representing $C1_I$ made by bulking and hand-pollinating remnant seed of the 1992 population of 194 full-sibs tested under the irrigated site,
Pop. 3	Representing $C1_{NI}$ made by bulking and hand-pollinating remnant seed of the 1992 population of 185 full-sibs tested under the nonirrigated site,
Syn 3I	Representing $C2_I$ for the irrigated site, made by bulking and hand-pollinating (by polycross) remnant seed of the 21 superior full-sibs selected in 1992
Syn 3NI	Representing $C2_{NI}$ for the nonirrigated site, made by bulking and hand-pollinating (by polycross) remnant seed of the 21 superior full-sibs selected in 1992
P X304C	Tropical hybrid from the Pioneer seed company
P 3320	Temperate hybrid from the Pioneer seed company
P 3394	Drought resistant temperate hybrid obtained from the Pioneer seed company
P 3165	Drought resistant temperate hybrid obtained from the Pioneer seed company

† I = selected under irrigated conditions
‡ NI = selected under nonirrigated conditions

same genotypes were planted in Waynesboro, TN under rainfed conditions on 14 April 1993.

The Florida sites were uniformly preplant harrowed and irrigated. Individual treatment plots in the March and May tests consisted of two rows 6.1 m long, spaced 0.76 m apart, and overplanted with 80 seed row^{-1}. The plots were later thinned at the four-leaf stage to 40 plants row^{-1} for a population of 86,000 plants ha^{-1}. In July, 40 kernels were planted in each two-row plot (3.05 m long) and later thinned to 20 plants row^{-1} for the same density of 86,000 plants ha^{-1}. The border rows were planted with an experimental hybrid (Howard-3) developed by Dr. R.N. Gallaher (personal communication).

The sites were fertilized with a preplanting dose of 575 kg ha^{-1} in the form of 12-4-8 ($N-P_2O_5-K_2O$). This fertilization was incorporated into the soil with the last harrowing. Two additional applications of 75 kg N ha^{-1}, and 49 kg N ha^{-1}, both in the form of Ammonium Nitrate, were broadcast and incorporated with a cultivator at 40 and 60 days after planting. An application of 42 kg P_2O_5 ha^{-1} in the form of Triple Superphosphate was applied on March 21.

Atrazine (*2-chloro-4-ethylamino-6-isopropylamino-s-triazine*) was applied as a preemergence herbicide at a rate of 2.2 kg a.i. ha^{-1}. Weed control was complemented with Atrazine plus an emulsifier-adjuvant oil applied at the same rate in the March plantings. Atrazine (2.2 kg ha^{-1}), Dual

[*Metolachlor:2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxyl-methylethyl)acetamide*] (11.2 kg ha^{-1}) and Gramoxone (*Paraquat dichloride (1,1'-dimethyl-4,4'-bypyridinium dichloride*) (1.1 kg ha^{-1}), were applied as preemergence in the May and July plantings. Irrigation was applied accordingly to the irrigated sites with overhead sprinklers and was withheld for the rainfed sites. Insects were controlled either with Furadan (*2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate*, 7.5 kg ha^{-1}) or Lannate [(*Methomyl:Methyl-N-[methylcarbamoyl(oxy)]thioacetimidate*, 2.2 kg ha^{-1})] bait, applied directly into the whorl of the corn plants.

At flowering total leaf number and leaf area measurements were collected on three plants $plot^{-1}$ by means of a leaf area meter (LI-COR model 3100). These measurements were used to determine leaf area index (LAI). Plant height and ear height were taken on these three plants. Plant height was measured from ground level to the flag leaf and recorded in meters. Ear height was the distance in meters between the base of the plants and the point of junction of the ears and the stems. Dates of 50% anthesis and silking were recorded.

Shortly after physiological maturity as determined as black layer formation (Daynard and Duncan, 1969), the ears of the entire plots were hand harvested. Grain yield was measured and expressed as kg ha^{-1} of grain at 15.5% moisture. Shelling percent and field moisture were collected. Harvested ears were dried in a forced air dryer to a uniform moisture

and shelled. The corn plants for each plot were cut and weighed for total dry matter (above ground) determinations. Samples were weighed and dried in a forced air dryer to a uniform moisture. Harvest index was taken as the ratio of dry grain yield to total dry matter yield.

Experimental Design and Statistical Analysis

Six experiments were performed to evaluate the experimental corn materials in a three-planting-date study in Florida. The three planting dates (March, May, and July) were chosen to mimic the use of corn in multiple cropping systems in Florida, the Southern USA, and similar environments around the world. At each date two experiments (one irrigated and one nonirrigated in two-row plots) were planted separately with the 12 entries (Table 27) in a completely randomized block design with 10 replications.

Analyses of variance were performed to evaluate the effects of genotype, planting dates, and their interaction on the measured traits. Data from each planting date were used in a combined analysis for each trait, computed across planting dates. The data from Tennessee were not included in these analyses. Statistical analyses were performed according to a split plot arrangement, with planting dates as main plots and genotypes as subplots. Differences in treatment means were detected by Duncan's Multiple Range Test (DMRT) for

comparison. Conclusions drawn from all tests of significance were based upon a 0.05 level of probability.

Rates of change were estimated from the slopes of the linear regressions of the quantitative traits on the selection cycles. For estimating gains per cycle, Syn 2I was pooled with Pop. 2 and Syn 2NI was combined with Pop. 3 to represent cycle C1, respectively developed under irrigated and rainfed conditions. Stability analysis was performed for grain yield and total plant dry matter according to the procedure proposed by Eberhart and Russell (1966). Planting dates, within a water regime, were considered as environments and the mean of all genotypes (the environmental index) at each date was regressed on the individual entry means. The Tennessee data were included in the stability analysis performed for the rainfed site. Phenotypic correlation coefficients (Pearson rank correlation) were computed for yield and the other variables by using means over planting dates. SAS procedures and programs were used for all statistical analyses (SAS, 1988).

Results and Discussion

Grain Yield and Total Dry Matter

Significant interaction ($p<0.01$) of genotypes by planting dates existed for grain yield in both the irrigated and rainfed environments (Tables 28 and 29). Date and genotype

Table 28. Mean squares from the combined analysis of variance over three planting dates for yield and other variables for 12 corn materials tested under irrigation in 1993, Gainesville, FL.

Source	df†	Yield	Total yield	Harvest index	Plant height	Ear height	Leaf area index	Leaf number
Reps‡	9	$1.4x10^6$	$6.7x10^6$	0.002	0.20	0.04	0.26	2.72
Date (D)	2	$1.6x10^9$**	$7.2x10^9$**	0.067**	3.56**	2.22**	49.80**	118.20**
Error(a)	18	$1.2x10^6$	$7.0x10^6$	0.001	0.08	0.03	2.00	3.06
Gen. (C)	11	$13x10^6$**	$119x10^6$**	0.052**	0.48**	0.53**	4.21**	15.60**
D x C	22	$16x10^6$**	$17x10^6$**	0.049**	0.04ns	0.03ns	0.33ns	0.72ns
Error(b)	96	$1.4x10^6$	$4.2x10^6$	0.001	0.03	0.02	0.37	0.65

*,** Significance at the 5% and 1% levels, respectively.
† df=degree of freedom
‡ Rep.= Replications; Gen.= Genotypes

Table 29. Means squares from the combined analysis of variance over three planting dates for yield and other variables for 12 corn materials tested without irrigation in 1993, Gainesville, FL.

Source	df†	Yield	Total yield	Harvest index	Plant height	Ear height	Leaf area index	Leaf number
Reps‡	9	$2.2x10^6$	$9.9x10^6$	0.002	0.19	0.18	1.06	2.72
Date (D)	2	$0.3x10^9$**	$3.4x10^9$**	0.201**	4.02**	3.60**	52.90**	3.93**
Error(a)	18	$2.1x10^6$	$11x10^6$	0.003	0.25	0.19	1.23	3.06
Gen. (C)	11	$5.1x10^6$**	$74x10^6$**	0.049**	0.33**	0.46**	2.14**	8.70**
D x C	22	$4.9x10^6$**	$24x10^6$**	0.015**	0.11**	0.14**	1.30**	3.45**
Error(b)	96	$0.6x10^6$	$2.4x10^6$	0.001	0.03	0.05	0.29	0.91

*,** Significance at the 5% and 1% levels, respectively.
† df=degree of freedom
‡ Rep.= Replications; Gen.= Genotypes

effects were also highly significant ($p<0.01$). The relative performance of the genotypes tested changed with planting dates (Tables 30 and 31). Decreases in grain yield were observed for all genotypes by delaying planting from March to July, except for Syn 3I of which yield increased slightly in May under irrigation. The March planting date was a better environment than the May and July, which were more limiting for the genotypes to express their yield potential.

Syn 3I (C2) was superior or comparable to Syn 3NI (C2), under either irrigated (Table 30) or rainfed (Table 31) plantings. Syn 3I had the highest yield for each planting date under irrigation. Syn 2I (C1) yielded less in the March rainfed environment, whereas Pop 1 (CO) yielded significantly less particularly in the March irrigated or rainfed planting. The genotypes selected under rainfed conditions (Syn 2NI, Syn 3NI) differed from Syn 3I only in the May environment under rainfed planting. This result suggests that the rainfed selections had not lost much of their yield potential and that the irrigated selection could perform well under drought stress as a derivative of its high yield potential. Under rainfed conditions, the hybrids outyielded the open-pollinated materials in the March environment. It seems that, besides drought, other factors (temperature, pest, maturity, or disease) also deserve consideration for each planting date.

The final experimental synthetics (Syn 3I and Syn 3NI) were similar in grain yield to Pioneer brands 3320 and 3394

Table 30. Genotype by planting date interaction effects on grain yield (at 15.5% moisture) of the 12 corn materials tested under irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			Average
	March	May	July	
	kg ha^{-1}			
Syn 1	9788 cdA†	7469 dB	4602 dC	7286
Pop. 1 (CO)	9760 cdA	9976 bcA	5456 bcB	8398
Pop. 2 ($C1_I$)	10127 bcB	11807 aA	5962 abC	9299
Syn 2I ($C1_I$)	8709 dA	8580 cdA	5662 bcB	7651
Pop. 3 ($C1_{NI}$)	8755 dB	11321 abA	5424 bcC	8500
Syn 2NI ($C1_{NI}$)	9760 cdA	8794 cdA	5421 bcB	7991
Syn 3I ($C2_I$)	10378 bcB	12156 aA	6297 aC	9610
Syn 3NI ($C2_{NI}$)	10145 bcA	8378 cdB	5327 bcC	7950
P X304C	11045 abA	9701 cB	5315 cC	8687
P 3320	10806 bcB	11872 aA	2294 fC	8324
P 3394	10644 bcA	9557 cB	4297 deC	8166
P 3165	11866 aA	11598 aA	3742 eB	9069
Average	10148.40	10100.70	4983.30	8411

† Mean yield values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level probability according to Duncan Multiple Range test.

Table 31. Genotype by planting date interaction effects on grain yield (at 15.5% moisture) of 12 corn materials tested without irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date March	May	July	Average
	----------kgha^{-1}----------			
Syn 1	6712 eA†	5482 dB	4696 abC	5630
Pop. 1 (CO)	7098 edA	6397 bcB	4521 abcC	6005
Pop. 2 ($C1_I$)	6740 eA	6128 cdA	4748 abB	5872
Syn 2I ($C1_I$)	7379 cdeA	5484 dB	4191 bcC	5685
Pop. 3 ($C1_{NI}$)	6696 eA	5778 cdB	4572 abcB	5682
Syn 2NI ($C1_{NI}$)	6892 eA	6386 bcA	4562 abcB	5947
Syn 3I ($C2_I$)	7534 cdeA	6411 aB	4987 aC	6311
Syn 3NI ($C2_{NI}$)	7876 bcdA	5586 dB	4609 abcC	6024
P X304C	8827 aA	7486 aB	4597 abcC	6970
P 3320	8192 abcA	6161 bcB	2587 eC	5647
P 3394	8804 aA	6973 abB	3991 cdC	6589
P 3165	8567 abA	6372 bcB	3438 dC	6126
Average	7610	6220	4292	6041

† Mean yield values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

but yielded less than Pioneer brands X304C and 3165 in the March irrigated planting. The performance of the temperate hybrids declined with late plantings, with Pioneer brand 3320 yielding the least in July. Pioneer brand X304C, which is recommended for late plantings in Florida, yielded less than Syn 3I in both May and July under irrigation. Syn 3NI was similar to Pioneer brand X304C.

The three effects (genotype, planting date, and their interaction) were highly significant ($p<0.01$) for total plant yield under both irrigated and rainfed environments (Tables 28 and 29)). Delayed planting decreased total plant yield for all the genotypes tested, more sharply in the July planting, with or without irrigation (Tables 32 and 33). The interaction was due to changes in ranks and magnitude.

Pop 1 (CO) produced less dry matter than Syn 3I and Syn 3NI only in the earlier planting of March under irrigation, but was comparable to Syn 3I irrespective of water regime and planting date. Syn 3NI produced less dry matter than Syn 3I and Pop 1 under the May and July rainfed environments. Pioneer brand X304C produced more total dry matter than the other cultivars, while Pioneer brands 3320 and 3394 were less productive at every planting date. The temperate hybrids produced less than the tropical hybrid and open-pollinated materials. The later plantings were more limiting for normal phenological development.

Table 32. Genotype by planting date interaction effects on total dry matter of 12 corn materials tested under irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			
	March	May	July	Average
	----------ton ha^{-1}----------			
Syn 1	22.3 cdeA†	19.1 deB	9.0 cdC	16.8
Pop. 1 (CO)	21.0 eB	23.3 bA	10.0 abcC	18.1
Pop. 2 ($C1_I$)	24.6 bcA	21.5 bcB	10.0 abcC	18.7
Syn 2I ($C1_I$)	23.9 bcdA	21.9 bB	9.9 abcB	18.5
Pop. 3 ($C1_{NI}$)	21.6 deA	19.5 cdB	9.4 cdC	16.8
Syn 2NI ($C1_{NI}$)	24.0 bcdA	22.1 bB	9.6 bcB	18.6
Syn 3I ($C2_I$)	25.9 bA	22.8 bB	11.0 aC	19.9
Syn 3NI ($C2_{NI}$)	25.5 bA	23.6 abB	9.2 cdC	19.4
P X304C	28.6 aA	25.4 aB	10.7 aC	21.6
P 3320	21.0 eA	17.1 eB	5.4 fC	14.5
P 3394	19.8 eA	17.9 deB	7.2 eC	15.0
P 3165	25.3 bA	19.2 deB	8.3 dC	17.6
Average	23.6	21.1	9.1	18.0

† Mean values of total dry matter within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range.

Table 33. Genotype by planting date interaction effects on total dry matter of 12 corn materials tested without irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			Average
	March	May	July	
	----------ton ha^{-1}----------			
Syn 1	18.9 bA†	14.2 edfB	8.23 abC	13.8
Pop. 1 (CO)	17.2 bcdA	17.5 bB	7.90 abC	14.2
Pop. 2 ($C1_I$)	13.6 fB	15.5 cdA	8.30 abC	12.5
Syn 2I ($C1_I$)	17.7 bcdA	13.8 efgB	8.21 abC	13.2
Pop. 3 ($C1_{NI}$)	18.8 bA	14.8 edB	7.50 bC	13.7
Syn 2NI ($C1_{NI}$)	17.8 bcdA	17.2 bA	8.15 abB	14.4
Syn 3I ($C2_I$)	17.9 bcdA	16.4 bcB	9.00 aC	14.4
Syn 3NI ($C2_{NI}$)	18.7 bcA	12.2 hB	7.20 bcC	12.7
P X304C	22.6 aA	20.5 aB	7.80 abC	17.0
P 3320	16.1 edA	12.9 fghB	4.40 eC	11.1
P 3394	16.9 cdeA	14.3 edfB	6.30 cdC	12.5
P 3165	15.4 eA	12.6 ghB	6.00 dC	11.4
Average	17.6	15.2	7.40	13.4

† Mean values of total dry matter within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

Planting date, genotype, and their interaction had highly significant effects ($p<0.01$) on harvest index (HI) (Tables 28 and 29). Later plantings resulted in larger values for HI for the genotypes tested with or without irrigation, due to lower vegetative growth (Tables 34 and 35). Pop 1 (CO) tended to have a lower HI in later plantings than the selected synthetics. Harvest index tended to be the highest for Syn 3NI as planting date was delayed under the rainfed environments.

Under irrigation the temperate hybrids had larger HI values than the tropical hybrid and open-pollinated materials. Pioneer brands 3320 and 3165 had the lowest HI values in the July irrigated planting. The open-pollinated materials had increased HI values with delayed planting, due to a higher decrease in vegetative growth. Under rainfed plantings, decreases were observed within the hybrids. The advanced selections had similar values as Pioneer brand X304C and similar values as CO in March.

Plant Height and Ear Height

Across planting dates, differences in plant height among the genotypes tested were highly significant ($p<0.001$) under irrigation (Table 28). These differences resulted in general from comparing the hybrids against the synthetics. There was no significant interaction between genotypes and planting dates. The genotypes tended to behave the same from one

Table 34. Genotype by planting date interaction effects on harvest index of 12 corn materials tested under irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			
	March	May	July	Average
Syn 1	0.44 dA†	0.39 fgB	0.44 cdA	0.42
Pop. 1 (CO)	0.46 cA	0.43 eA	0.46 bcA	0.45
Pop. 2 ($C1_I$)	0.41 eC	0.55 cdA	0.50 aB	0.49
Syn 2I ($C1_I$)	0.36 gB	0.39 fgB	0.49 abA	0.41
Pop. 3 ($C1_{NI}$)	0.41 efC	0.58 bcA	0.49 abB	0.49
Syn 2NI ($C1_{NI}$)	0.41 efB	0.40 efB	0.48 abA	0.43
Syn 3I ($C2_I$)	0.40 efC	0.53 dA	0.49 abB	0.47
Syn 3NI ($C2_{NI}$)	0.40 efB	0.36 gC	0.49 abA	0.42
P X304C	0.39 fB	0.38 fgB	0.42 dA	0.40
P 3320	0.52 bB	0.63 aA	0.37 eC	0.50
P 3394	0.54 aA	0.60 dA	0.50 aB	0.52
P 3165	0.47 cB	0.60 abA	0.38 eC	0.49
Average	0.43	0.48	0.46	0.46

† Mean harvest index values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

Table 35. Genotype by planting date interaction effects on harvest index of 12 corn materials tested without irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			
	March	May	July	Average
Syn 1	0.35 dC†	0.39 defB	0.49 cA	0.40
Pop. 1 (CO)	0.41 cB	0.37 fC	0.49 cA	0.42
Pop. 2 ($C1_I$)	0.50 bA	0.40 dB	0.49 cA	0.46
Syn 2I ($C1_I$)	0.42 cAB	0.40 dB	0.44 dA	0.42
Pop. 3 ($C1_{NI}$)	0.36 dC	0.39 deB	0.53 abA	0.42
Syn 2NI ($C1_{NI}$)	0.39 cB	0.37 efB	0.48 cA	0.41
Syn 3I ($C2_I$)	0.42 cB	0.39 deC	0.47 cA	0.43
Syn 3NI ($C2_{NI}$)	0.42 cC	0.46 cB	0.55 aA	0.47
P X304C	0.39 cB	0.37 fB	0.50 bcA	0.42
P 3320	0.50 bA	0.48 bA	0.50 bcA	0.49
P 3394	0.53 bA	0.49 bB	0.54 aA	0.52
P 3165	0.56 aA	0.50 aB	0.49 cB	0.52
Average	0.44	0.42	0.50	0.45

† Mean harvest index values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

planting date to another. Pioneer brand X304C and the open-pollinated materials were similar in plant height. The temperate hybrids were shorter than the tropical hybrid and open-pollinated materials.

Planting date effect was highly significant ($p<0.01$) when compared across cultivars (Table 28). Delaying planting from May to July resulted in shorter plants from 2.60 m to 2.09 m, but not from March to May (Table 36).

Significant interaction ($p<0.001$) was obtained for plant height by planting under rainfed conditions (Table 29). No differences were observed among the cycles of selection in the March and May rainfed plantings (Table 38). However, Pop 1 (with 2.03 m) was taller than Syn 3NI (with 1.72 m). The interaction resulted from a change in ranking and magnitude in plant height in the July planting. Syn 2I ranked first with 2.05 m while Syn 3NI ranked last with 1.72 m. The July planting produced shorter plants than the March and May planting dates for all the cycles of selection.

The synthetics had similar plant height as Pioneer brand X304C under the March rainfed environment and grew taller than the temperate hybrids. Pioneer brand 3394 was the shortest in the March and May rainfed environments. In the July planting, Syn 3NI was the shortest among the materials tested. The temperate hybrids and some of the selections were the tallest.

Ear height followed the same pattern as plant height. The irrigated environments resulted in significant genotype and

Table 36. Effects of planting date and genotype on plant height of 12 corn materials tested under irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date March	May	July	Average
	----------m----------			
Syn 1	2.73	2.64	2.30	2.56 A†
Pop. 1 (CO)	2.60	2.70	2.20	2.50 AB
Pop. 2 ($C1_I$)	2.60	2.70	2.20	2.50 AB
Syn 2I ($C1_I$)	2.47	2.70	2.12	2.42 B
Pop. 3 ($C1_{NI}$)	2.55	2.70	2.10	2.45 B
Syn 2NI ($C1_{NI}$)	2.60	2.60	2.19	2.46 B
Syn 3I ($C2_I$)	2.55	2.80	2.19	2.50 AB
Syn 3NI ($C2_{NI}$)	2.70	2.83	2.13	2.54 AB
P X304C	2.75	2.82	2.25	2.60 A
P 3320	2.30	2.35	1.70	2.09 CD
P 3394	2.24	2.08	1.64	2.00 D
P 3165	2.26	2.20	2.06	2.20 C
Average	2.52 A	2.60 A	2.09 B	2.40

† Mean plant height values for genotypes and planting dates not marked with the same letter (A, B, C) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

Table 37. Genotype by planting date interaction effects on plant height of of 12 corn materials tested without irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes		Planting Date March		May		July		Average
		----------			m			----------
Syn 1		2.60	aA†	2.72	aA	2.02	abcB	2.44
Pop. 1	(CO)	2.40	abcA	2.60	bA	2.03	abcB	2.35
Pop. 2	($C1_I$)	2.14	bcdB	2.70	abA	1.90	abcdB	2.25
Syn 2I	($C1_I$)	2.33	abcdB	2.57	bA	2.05	abC	2.32
Pop. 3	($C1_{NI}$)	2.50	abA	2.60	abA	2.10	aA	2.40
Syn 2NI	($C1_{NI}$)	2.40	abc	2.60	abA	1.81	cdB	2.30
Syn 3I	($C2_I$)	2.50	abA	2.55	bA	1.90	abcdB	2.32
Syn 3NI	($C2_{NI}$)	2.43	abcB	2.68	abA	1.72	dC	2.30
P X304C		2.40	abcB	2.80	aA	1.96	abcC	2.40
P 3320		2.02	d A	2.21	cA	2.05	abA	2.09
P 3394		1.70	eA	2.02	cA	1.94	abcA	1.90
P 3165		2.10	cdA	2.20	cA	1.83	bcdA	2.04
Average		2.30		2.52		1.94		2.25

† Mean plant height values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

date effects only (Table 28). No interaction was detected. With irrigation, the nonirrigated and irrigated synthetics were not different in ear height from Pop 1 (Table 38). Pioneer brand X304C had similar ear height as the advanced selections. The ears of the temperate hybrids were at a significantly lower position on the stalk than those of the tropical materials.

A highly significant interaction ($p<0.01$) was observed for ear height under the rainfed environments (Table 29), which was due to a change in magnitude and ranking among the cultivars. Differences were not obtained among the cycles within planting dates (Table 39). Reductions were observed by delaying planting from March to July. Syn 3NI had the highest ears in the March and May plantings, but fell among the lowest by delaying planting in July. Pioneer brand X304C had the highest ears at each planting date. The temperate hybrids tended to have lowest ears in March and May, but were among the genotypes with the highest ears in July. No differences among the genotypes were observed in the July environment.

Leaf Area Index and Leaf number

For leaf area index, the date and genotype effects were highly significant ($p<0.01$) under irrigation. No interaction was observed between cultivar and planting date (Table 28). However, no difference was obtained among the cycles or synthetics themselves and when compared with the

Table 38. Effects of planting date and genotype on ear height of 12 corn materials tested under irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date March	May	July	Average
	----------m----------			
Syn 1	1.65	1.72	1.33	1.56 A†
Pop. 1 (CO)	1.65	1.54	1.21	1.50 AB
Pop. 2 ($C1_I$)	1.72	1.60	1.20	1.49 AB
Syn 2I ($C1_I$)	1.68	1.45	1.16	1.43 B
Pop. 3 ($C1_{NI}$)	1.80	1.52	1.21	1.50 AB
Syn 2NI ($C1_{NI}$)	1.58	1.53	1.18	1.43 B
Syn 3I ($C2_I$)	1.74	1.52	1.20	1.49 AB
Syn 3NI ($C2_{NI}$)	1.80	1.56	1.21	1.52 AB
P X304C	1.65	1.60	1.22	1.49 AB
P 3320	1.18	1.12	1.08	1.13 C
P 3394	1.10	0.99	0.70	0.93 C
P 3165	1.09	1.17	0.94	1.06 C
Average	1.55 B	1.44 A	1.14 C	1.40

‘ Mean ear height values for genotypes and planting dates not marked with the same letter (A, B, C) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

Table 39. Genotype by planting date interaction effects on ear height of 12 corn materials tested without irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			
	March	May	July	Average
	----------	m	----------	
Syn 1	1.80 aA†	1.52 aA	1.02 aB	1.44
Pop. 1 (CO)	1.43 aA	1.43 abA	1.00 aB	1.35
Pop. 2 ($C1_I$)	1.63 aA	1.63 aA	0.93 aB	1.39
Syn 2I ($C1_I$)	1.58 aB	1.26 bcA	1.09 aB	1.31
Pop. 3 ($C1_{NI}$)	1.45 aA	1.45 abA	1.14 aA	1.55
Syn 2NI ($C1_{NI}$)	1.58 aA	1.42 abA	0.84 aB	1.30
Syn 3I ($C2_I$)	1.57 aA	1.41 abA	0.93 aB	1.30
Syn 3NI ($C2_{NI}$)	1.67 aA	1.39 abA	0.84 aB	1.30
P X304C	1.61 aA	1.32 bA	0.93 aB	1.30
P 3320	1.00 bA	0.86 deA	0.99 aA	0.95
P 3394	1.06 bA	0.68 eB	0.98 aA	0.90
P 3165	1.05 bA	1.02 cdA	0.98 aA	1.02
Average	1.52	1.28	0.97	1.26

† Mean ear height values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

tropical hybrid (Pioneer brand X304C) for a range from 5.6 to 5.9 (Table 40). The temperate hybrids had significantly lower LAI values (ranging from 4.2 to 4.7 m) than the tropical hybrid and open-pollinated cultivars.

All of the LAI effects were highly significant ($p<0.01$) with no irrigation (Table 41). Changes in rank and in magnitude caused this cultivar by planting date interaction (Table 41). The differences appeared in the May planting where Pop 1 and Syn 3NI had higher LAI values than Syn 3I. In the July planting Syn 3NI had a lower LAI value than Pop 1 and Syn 3I. Pioneer brand X304C had high values of LAI in March and May. The temperate hybrids significantly had the lowest LAI values. The differences tended to disappear in the July environment, confirming that the environment had a strong effect on the corn materials investigated.

No interaction was observed for leaf number between cultivar and planting date under irrigation (Table 28). Even though leaf numbers decreased from the March to the July plantings, no differences were obtained among the cycles of selection and Pioneer brand X304C (Table 42). Pioneer brands 3320 and 3165 had more leaves than Pioneer brand 3394. Under rainfed planting, the interaction had a highly significant effect on leaf numbers (Table 29), due to changes in rankings and magnitude. No differences were observed among the synthetics or cycles of selection in March and May (Table 43). Syn 3NI carried significantly fewer leaves in July than the

Table 40. Effects of planting date and genotype on leaf area index of 12 corn materials tested under irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			Average
	March	May	July	
Syn 1	6.22	6.00	4.90	5.70 A†
Pop. 1 (CO)	6.42	6.00	4.35	5.60 A
Pop. 2 ($C1_I$)	6.65	6.00	4.60	5.80 A
Syn 2I ($C1_I$)	6.70	5.70	4.60	5.70 A
Pop. 3 ($C1_{NI}$)	6.40	6.20	4.40	5.60 A
Syn 2NI ($C1_{NI}$)	7.10	5.60	4.60	5.75 A
Syn 3I ($C2_I$)	6.40	6.40	4.70	5.80 A
Syn 3NI ($C2_{NI}$)	6.80	6.30	4.50	5.90 A
P X304C	6.70	6.35	4.40	5.80 A
P 3320	5.70	4.30	3.50	4.50 BC
P 3394	5.00	4.30	3.20	4.20 C
P 3165	5.60	4.70	3.90	4.70 B
Average	6.30 A	5.65 A	4.30 B	5.42

† Mean leaf area index values for genotypes and planting dates not marked with the same letter (A, B, C) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

Table 41. Genotype by planting date interaction effects on leaf area index of 12 corn materials tested without irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes		Planting Date March		May		July		Average
Syn 1		5.70	abcA†	5.60	aA	3.50	abcdB	4.90
Pop. 1	(CO)	5.60	abcA	5.10	abA	3.50	abcB	4.70
Pop. 2	($C1_I$)	5.60	abcA	5.80	aA	3.20	bcdB	4.80
Syn 2I	($C1_I$)	5.55	abcA	5.80	aA	3.50	abcB	4.95
Pop. 3	($C1_{NI}$)	6.10	aA	5.60	aA	4.00	aB	5.30
Syn 2NI	($C1_{NI}$)	5.30	bcA	4.80	abcA	2.90	cdB	4.30
Syn 3I	($C2_I$)	5.90	abA	4.40	bcdB	3.30	abcdC	4.50
Syn 3NI	($C2_{NI}$)	5.50	abcA	5.80	aA	2.70	bB	4.70
P X304C		5.00	cdA	5.25	abA	3.35	abcdB	4.50
P 3320		4.50	dA	3.70	dB	3.95	abAB	4.10
P 3394		3.60	eA	4.00	cdA	3.60	abcA	3.70
P 3165		5.50	abcA	4.40	bcdB	3.05	cdC	4.30
Average		5.31		5.02		3.40		4.60

† Mean leaf area index values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

Table 42. Effects of planting date and genotype on leaf number of 12 corn materials tested under irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes	Planting Date			
	March	May	July	Average
	----------no----------			
Syn 1	16.20	16.75	14.40	15.80 A†
Pop. 1 (CO)	16.10	17.10	14.10	15.70 A
Pop. 2 ($C1_I$)	15.40	17.70	13.90	15.70 A
Syn 2I ($C1_I$)	15.90	16.60	14.20	15.60 A
Pop. 3 ($C1_{NI}$)	15.60	17.80	13.60	15.70 A
Syn 2NI ($C1_{NI}$)	15.50	17.00	14.40	15.60 A
Syn 3I ($C2_I$)	16.15	17.90	13.65	15.90 A
Syn 3NI ($C2_{NI}$)	16.15	18.20	14.50	16.30 A
P X304C	15.85	17.40	13.90	15.70 A
P 3320	14.40	15.20	12.30	13.95 B
P 3394	12.70	13.20	11.00	12.30 C
P 3165	14.20	15.60	12.85	14.20 B
Average	15.30 B	16.70 A	13.60 C	15.20

† Mean leaf area index values for genotypes and planting dates not marked with the same letter (A, B, C) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

Table 43. Genotype by planting date interaction effects on leaf number of 12 corn materials tested without irrigation in 1993 at Green Acres farm, Gainesville, FL.

Genotypes		Planting Date March	May	July	Average
		----------no----------			
Syn 1		17.25 aA†	16.50 abcA	13.80 aB	15.85
Pop. 1	(CO)	17.10 aA	16.20 abcA	12.55 abcB	15.30
Pop. 2	($C1_I$)	16.50 aA	17.80 aA	12.85 abB	15.70
Syn 2I	($C1_I$)	16.50 aA	16.70 abA	12.60 abcB	15.25
Pop. 3	($C1_{NI}$)	17.40 aA	16.25 abcA	13.65 abB	15.75
Syn 2NI	($C1_{NI}$)	17.00 aA	16.40 abcA	12.80 abB	15.40
Syn 3I	($C2_I$)	16.40 aA	16.50 abcB	13.10 abC	15.30
Syn 3NI	($C2_{NI}$)	16.50 aA	17.50 aA	11.30 cB	15.10
P X304C		16.50 aA	16.70 abA	13.50 abB	15.60
P 3320		14.40 bA	14.50 cdA	13.90 aA	14.30
P 3394		13.10 cA	13.10 dA	12.60 abcA	12.90
P 3165		15.30 bA	14.90 bcA	12.30 bcB	14.20
Average		16.20	16.10	12.90	15.05

† Mean leaf number values within a row not marked with the same large letter (A, B, C), and averages for genotypes within a date not marked with the same small letter (a, b, c) are significantly different at the 0.05 level according to Duncan's Multiple Range test.

other selections. The temperate hybrids were among the genotypes with the largest numbers of leaves. Decreases in leaf number were obtained only by delaying planting to July.

Realized Gains

In irrigated environments, grain yield showed a linear increase of 606 kg ha^{-1} (7.22%) $cycle^{-1}$ due to selection under irrigation. A linear decrease of -224 kg ha^{-1} in grain yield (-2.67%) $cycle^{-1}$ was obtained by selecting under rainfed conditions (Table 44 and Figure 9). Selecting under the rainfed environment was accompanied with a grain yield sacrifice under irrigated conditions. Under rainfed environments, the linear increases were 153 kg ha^{-1} (2.55%) $cycle^{-1}$ and 9.50 kg ha^{-1} (0.16%) $cycle^{-1}$ by selecting under irrigated and rainfed environments, respectively (Table 45 and Figure 10).

A faster progress was realized under the irrigated than under the nonirrigated environment. Averaged across the water and date environments, an overall gain of 5.20% $cycle^{-1}$ was realized for grain yield by selecting under irrigation (Table 46). A overall decrease of -1.49% $cycle^{-1}$ was obtained by selecting without irrigation. Several researchers (Arboleda-Rivera and Compton, 1974; Johnson and Geadelmann, 1989) have reported faster advances when selecting under good environments in comparison with poor environments. This

Table 44. Effect of selection on grain yield (15.5% moisture) of the five experimental synthetics representing cycles C0, C1, and C2, tested under irrigation in 1993, Gainesville, FL.

Synthetics	Cycles	Grain yield	Gain	
			Realized	Expected
		kg ha^{-1}	% $cycle^{-1}$	----%----
Pop 1	0	8398†		
Syn 2I,Pop2‡	1	8475		13.3
Syn 3I	2	9610	7.22§	19.0
Pop 1	0	8398		
Syn 2NI,Pop3‡	1	8246		-
Syn 3NI	2	7950	-2.67	-

† Averages across planting dates for irrigated environments
‡ Mean values of these two populations are the figures used for cycles C1 for each specific environment; I = Selections with irrigation; NI = Selections without irrigation
§ Gains $cycle^{-1}$ are based on the slope of linear regression

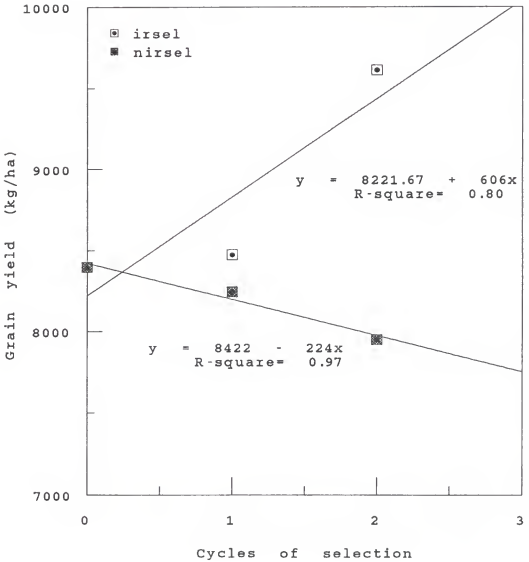

Figure 9. Effect of selection on grain yield of experimental synthetics selected under irrigated or rainfed conditions and tested under irrigation in 1993 at Green Acres, Gainesville, FL. Irsel=Irrigated selection; Nirsel=Nonirrigated selection

Table 45. Effect of selection on grain yield (15.5% moisture) of the five experimental synthetics representing cycles C0, C1, and C2, tested without irrigation in 1993, Gainesville, FL.

Synthetics	Cycles	Grain yield	Gain	
			Realized	Expected
		kg ha^{-1}	% $cycle^{-1}$	----%---
Pop 1	0	6005†		
Syn 2I,Pop2‡	1	5779		-
Syn 3I	2	6311	2.55§	-
Pop 1	0	6005		
Syn 2NI,Pop 3‡	1	5815		12.7
Syn 3NI	2	6024	0.16	9.4

† Averages across planting dates for irrigated environments
‡ Mean values of these populations are the figures used for cycles C1 for each specific environment; I = Selections with irrigation; NI = Selections without irrigation
§ Gains $cycle^{-1}$ are based on the slope of linear regression

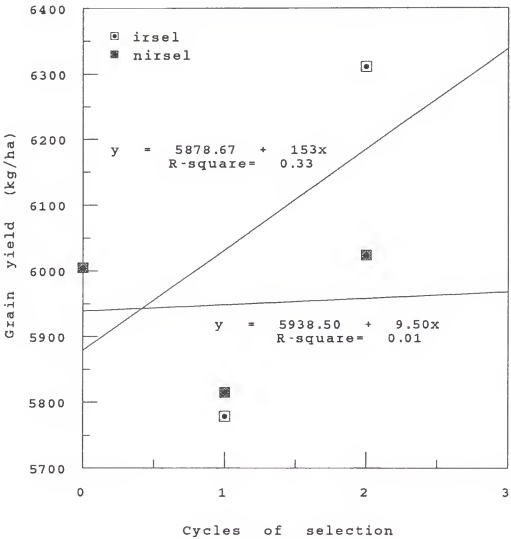

Figure 10. Effect of selection on grain yield of synthetics selected under irrigated or rainfed conditions and tested in rainfed environments in 1993 at Green Acres, Gainesville, FL. Irsel=Irrigated selection; Nirsel=Nonirrigated selection

Table 46. Overall effect of selection on grain yield (15.5% moisture) of the experimental synthetics representing cycles C0, C1, and C2, tested in 1993, Gainesville, FL.

Synthetics	Cycles	Grain yield	Realized gain
		kg ha^{-1}	% $cycle^{-1}$
Pop 1	0	7201†	
Syn 2I,Pop2‡	1	7127	
Syn 3I	2	7950	5.20§
Pop 1	0	7201	
Syn 2NI,Pop3‡	1	7031	
Syn 3NI	2	6987	-1.49

† Averages across planting dates and water environments
‡ Mean values of these two populations are the figures used for cycles C1 for each specific environment; I = Selections with irrigation; NI = Selections without irrigation
§ Gains $cycle^{-1}$ are based on the slope of linear regression

differential response was reported to be due to the decline in heritability observed in stress environments (Blum, 1988). Other authors (Falconer, 1981; Ceccarelli et al., 1987) advocated a superior efficiency of selection under moisture stress conditions when the objective is to identify genotypes for drought environments.

For total dry matter, testing under irrigation revealed overall linear increases of 0.90 ton ha^{-1} (4.97%) $cycle^{-1}$ and 0.65 ton ha^{-1} (3.59%) $cycle^{-1}$ for the respective irrigated and rainfed selections (Table 47 and Figure 11). However, selecting in irrigated conditions resulted in a nonsignificant increase of 0.70% $cycle^{-1}$ under nonirrigated conditions, whereas a significant decrease of -5.28% $cycle^{-1}$ resulted from selecting under rainfed environments (Table 48 and Figure 12).

The effects of selecting under irrigation on HI showed a significant linear increase of 6% per cycle in trials conducted under irrigated conditions (Table 49). No improvement in HI was registered for the rainfed selections tested under irrigation. An improvement of 0.01 (2.5%) $cycle^{-1}$ was obtained with the irrigated selections tested under rainfed conditions (Table 50 and Figure 13). A better gain was obtained for the rainfed selections tested in rainfed environments. An overall increase of 14.6% per cycle was realized (Table 50 and Figure 14). A 25% increase in yield of tropical corn is possible if HI can be increased from 0.40 (common in tropical materials) (Fischer et al., 1987) to the

Table 47. Effect of selection on total dry matter of the five experimental synthetics representing cycles C0, C1, and C2, tested under irrigation in 1993, Gainesville, FL.

Synthetics	Cycles	TDM†	Gain	
			Realized	Expected
		ton ha^{-1}	% $cycle^{-1}$	---%--
Pop 1	0	18.10		
Syn 2I,Pop 2‡	1	18.60		8.6
Syn 3I	2	19.90	4.97§	-
Pop 1	0	18.10		
Syn 2NI,Pop 3‡	1	17.70		-
Syn 3NI	2	19.40	3.59	-

† TDM = Total dry matter averages across planting dates for irrigated environments

‡ Mean values of these populations are the figures used for cycles C1 for each specific environment; I = Selections with irrigation; NI = Selections without irrigation

§ Gains $cycle^{-1}$ are based on the slope of linear regression

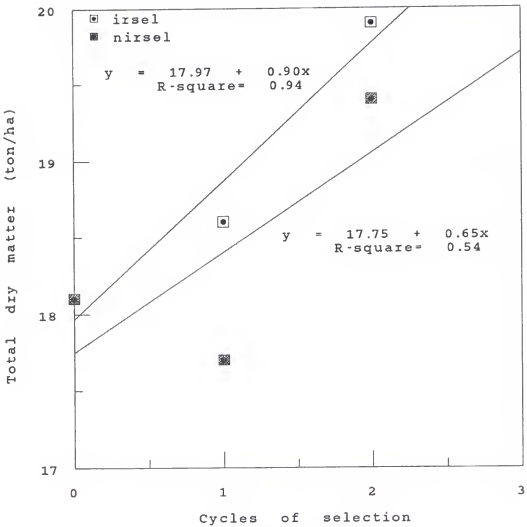

Figure 11. Effect of selection on total dry matter of the experimental synthetics selected under irrigated or rainfed conditions and tested under irrigation in 1993 at Green Acres, Gainesville, FL. Irsel=Irrigated selection; Nirsel=Nonirrigated selection

Table 48. Effect of selection on total dry matter of the five experimental synthetics representing cycles C0, C1, and C2, tested without irrigation in 1993, Gainesville, FL.

Synthetics	Cycles	TDM†	Gain	
			Realized	Expected
		ton ha^{-1}	% $cycle^{-1}$	---%---
Pop 1	0	14.20		
Syn 2I,Pop 2‡	1	12.85		-
Syn 3I	2	14.40	0.70§	-
Pop 1	0	14.20		
Syn 2NI,Pop 3‡	1	14.05		8.0
Syn 3NI	2	12.70	-5.28	-

† Averages across planting dates for irrigated environments
‡ Mean values of these populations are the figures used for cycles C1 for each specific environment; I = Selections with irrigation; NI = Selections without irrigation
§ Gains $cycle^{-1}$ are based on the slope of linear regression

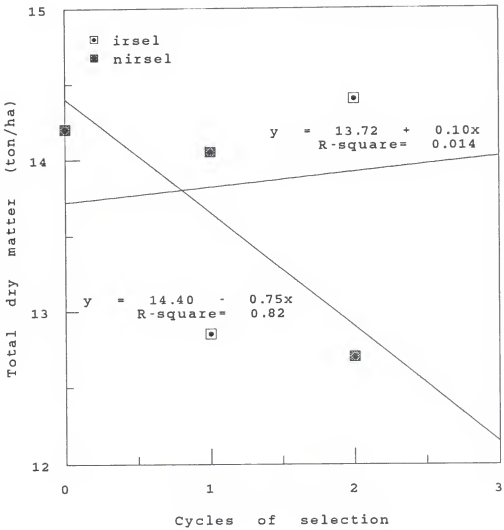

Figure 12. Effect of selection on total plant dry matter of the experimental synthetics selected in irrigated or rainfed conditions and tested without irrigation in 1993, Gainesville, FL. Irsel=Irrigated selection; Nirsel=Nonirrigated selection

Table 49. Effect of selection on harvest index of the five experimental synthetics representing cycles C0, C1, and C2, tested under irrigation in 1993, Gainesville, FL.

Synthetics	Cycles	Harvest index†	Gain	
			Realized	Expected
			% cycle^{-1}	---%---
Pop 1	0	0.45		
Syn 2I,Pop 2‡	1	0.45		11.0
Syn 3I	2	0.47	2.22§	-
Pop 1	0	0.45		
Syn 2NI,Pop 3‡	1	0.46		-
Syn 3NI	2	0.42	-3.33	-

† Averages across planting dates for irrigated environments
‡ Mean values of these populations are the figures used for cycles C1 for each specific environment; I = Selections with irrigation; NI = Selections without irrigation
§ Gains cycle^{-1} are based on the slope of linear regression

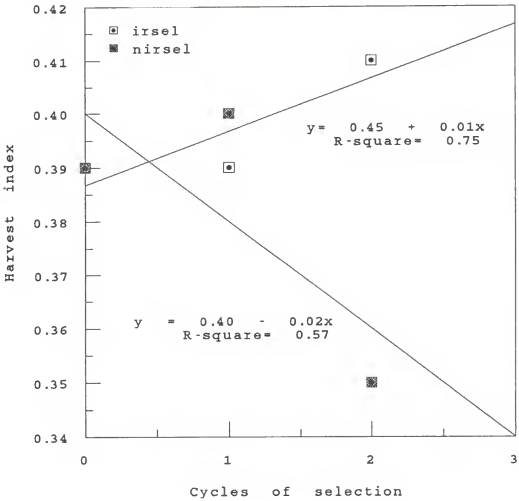

Figure 13. Effect of selection on harvest index of the experimental synthetics selected in irrigated or rainfed conditions and tested under irrigation in 1993, Gainesville, FL. Irsel=Irrigated selection; Nirsel=Nonirrigated selection

Table 50. Effect of selection on harvest index of the five experimental synthetics representing cycles C0, C1, and C2, tested without irrigation in 1993, Gainesville, FL.

Synthetics	Cycles	Harvest index†	Gain	
			Realized	Expected
			% cycle^{-1}	---%---
Pop 1	0	0.42		
Syn 2I,Pop 2‡	1	0.44		-
Syn 3I	2	0.43	1.19§	-
Pop 1	0	0.42		
Syn 2NI,Pop 3‡	1	0.42		7.0
Syn 3NI	2	0.47	5.95	-

† Averages across planting dates for irrigated environments Mean values of these populations are the figures used for cycles C1 for each specific environment; I = Selections with irrigation; NI = Selections without irrigation

§ Gains cycle^{-1} are based on the slope of linear regression

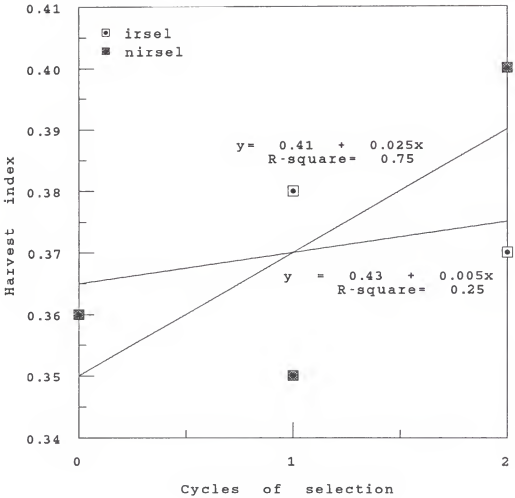

Figure 14. Effect of selection on harvest index of the experimental synthetics selected in irrigated or rainfed conditions and tested without irrigation in 1993, Gainesville, FL. Irsel=Irrigated selection; Nirsel=Nonirrigated selection

0.50 level of temperate materials (Russell, 1985; Fakorede and Mock, 1978). For irrigated environments, our material increased from 0.41 (CO) to 0.47 (Syn 3I), and from 0.41 (CO) to 0.43 (Syn 3I) or 0.47 (Syn 3NI) in rainfed environments. Barrenness was not a problem in our study since significant moisture stress was not placed at flowering upon the full-sibs. This was confirmed by Bolanos and Edmeades (1990).

Selecting for yield in irrigated condition was not accompanied by significant changes in plant height (Table 51) in trials carried out in irrigated or rainfed environments. Selecting under rainfed conditions resulted in an overall decrease in plant height of 0.08 m (3.3%) per cycle only in rainfed environments (Table 52). Bolanos et al. (1993) observed a negative indirect response for plant height, resulting from a reduction in days to flowering, as a drought escape mechanism of early-flowering full-sib families. Johnson et al. (1986) obtained a 4.4% $cycle^{-1}$ increase in grain yield at the optimum plant density as a result of a 2.4% $cycle^{-1}$ decrease in plant height.

Significant and similar decreases in ear height were observed for the first cycles of selection (both irrigated and rainfed selections) when tested under irrigated conditions. The respective change was -3.1% per cycle for both cases (Table 51). When tested in rainfed environments, a similar

Table 51. Effect of selection on plant height, ear height, and leaf area index of the experimental synthetics representing cycles C0, C1, and C2, tested under irrigation in 1993, Gainesville, FL.

Cycles†	Plant height	Ear height	Leaf area index
	----------m----------		
For selections under irrigation			
C0	2.50‡	1.50	5.60
C1	2.46	1.46	5.75
C2	2.50	1.49	5.80
Gain(%)§	0.00(2.8)	0.33(3.4)	1.72(2.4)
For selections without irrigation			
C0	2.50	1.50	5.60
C1	2.46	1.47	5.70
C2	2.54	1.52	5.90
Gain	0.80	0.67	2.68

† Selections with irrigation:
C0 = Pop 1; C1 = Syn 2I combined with Pop 2; C2 = Syn 3I
Selections without irrigation:
C0 = Pop 1; C1 = Syn 2NI combined with Pop 3;
‡ Averages across planting dates
§ Gains $cycle^{-1}$ are based on the slope of linear regression
Data in parentheses are expected gains

Table 52. Effect of selection on plant height, ear height, and leaf area index of the experimental synthetics representing cycles C0, C1, and C2, tested without irrigation in 1993, Gainesville, FL.

Cycles†	Plant height	Ear height	Leaf area index
	----------m----------		
For selections under irrigation			
C0	2.35‡	1.35	4.70
C1	2.29	1.35	4.90
C2	2.32	1.30	4.50
Gain(%)§	-0.64	-1.85	-2.13
For selections without irrigation			
C0	2.35	1.35	4.70
C1	2.35	1.33	4.80
C2	2.28	1.30	4.70
Gain(%)	-1.49(-1.2)	-1.85(-2.5)	0.00(-4.6)

† Selections with irrigation:
C0 = Pop 1; C1 = Syn 2I combined with Pop 2; C2 = Syn 3I
Selections without irrigation:
C0 = Pop 1; C1 = Syn 2NI combined with Pop 3; C2 = Syn 3NI
‡ Averages across planting dates
§ Gains cycle^{-1} are based on the slope of linear regression
Data in parentheses are expected gains

change of -4.9% per cycle was obtained for both the synthetics selected under irrigated and rainfed conditions (Table 52).

No significant changes in LAI were realized from selecting for high grain and total plant yield under irrigated conditions (Table 51). Gains of 1.72% and 2.68% $cycle^{-1}$ were obtained with irrigation for the respective irrigated and rainfed selections. A loss of -2.13% $cycle^{-1}$ was realized with the irrigated selections under rainfed conditions (Table 52).

No significant changes in leaf numbers were realized from selecting under irrigated or rainfed environments. Bolanos et al. (1993) obtained significant responses in final leaf numbers of -0.11 leaf $cycle^{-1}$. The loss per cycle in LAI obtained with rainfed selection might have been due to reductions in leaf size by selecting for drought resistance in rainfed conditions.

Stability Analyses

The stability analyses of grain yield on environment mean yield were very linear (Figures 15, 16, and 17). No differences were observed between C0 and the C1's in grain yield stability (Figure 16). The final experimental synthetic (Syn 3NI) with the lowest yield potential tended to have the smallest regression coefficients (b = 0.81) among the open-pollinated materials. Syn 3I with the highest yield potential had the highest regression coefficient (b = 1.04) and consequently the largest yield reductions due to its

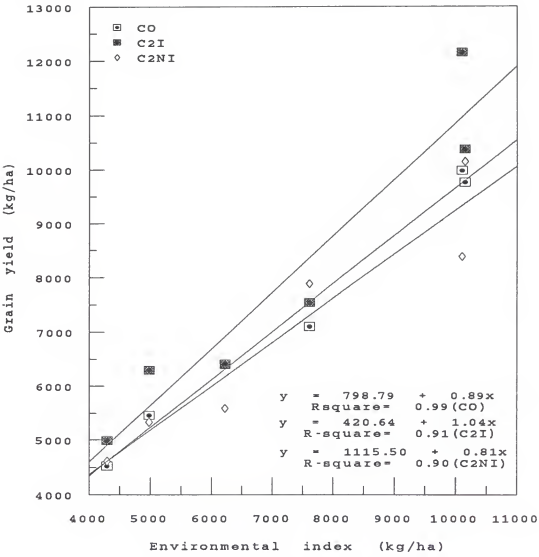

Figure 15. Grain yield stability of CO in comparison with $C2_I$ and $C2_{NI}$ tested in irrigated and rainfed environments in 1993, Gainesville, FL. CO = Pop 1; $C2_I$ = Syn 3I; $C2_{NI}$ = Syn 3NI

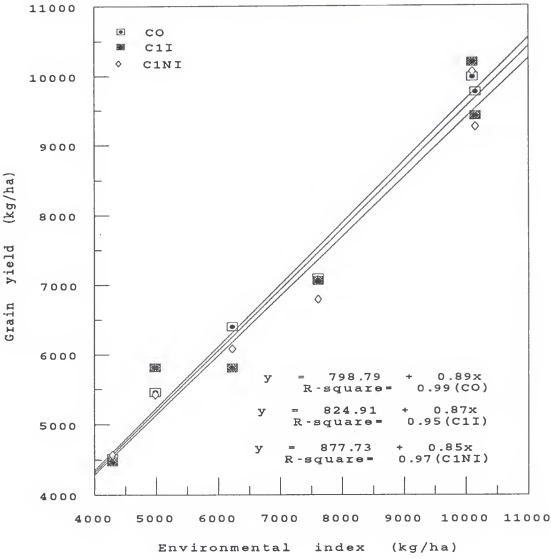

Figure 16. Grain yield stability of Pop 1 (CO) in comparison with $C1_I$ and $C1_{NI}$ tested in irrigated and rainfed environments in 1993, Gainesville, FL. $C1_I$ = Average of Pop 2 and Syn 2I; $C1_{NI}$ = Average of Pop 3 and Syn 2NI.

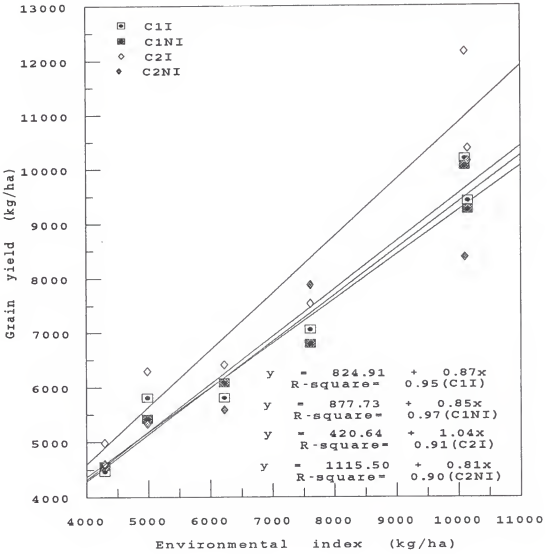

Figure 17. Grain yield stability of cycles C1's in comparison with cycles C2's tested under irrigated and rainfed environments in 1993, Gainesville, FL. $C1_I$ = Average of Pop 2 and Syn 2I; $C1_{NI}$ = Average of Pop 3 and Syn 2NI; $C2_I$ = Syn 3I; $C2_{NI}$ = Syn 3NI.

largest increases in better environments. Although it yielded considerably better in high-yielding environments, Syn 3I tended to also perform better in low-yielding environments (Fig 15 and 17). Syn 3NI (b = 0.81) performed poorer than CO (b = 0.89) in either poor or good environments. Syn 3I ($C2_I$) which excelled in high yield situations would be a good choice for both rainfed and irrigated environments due to its high potential. The differences were larger between the C2's and CO than between the C1's and CO as would be expected. The linear regression analyses accounted for most of the variation in grain yield, which made them useful in quantifying the adaptation of the cultivars to the imposed environments.

For total dry matter, stability analyses revealed that Syn 3NI had the ability to decrease its vegetative growth under water stress environments and performed as well as Syn 3I (the highest yielder) in well-watered environments (Figures 18, 19 and 20). It also had the larger regression coefficient (b = 1.16). Pop 1 (CO) might have derived its low yield ability from its low vegetative growth (b= 0.90) in high-yielding environments.

The temperate hybrids, Pioneer brands 3320 and 3165, were unstable cultivars with respective b-values of 1.58 and 1.47, giving low yields in poor environments but high yields in favorable environments (Figure 21). Pioneer brand 3394 was more stable (with a b-value of 1.06) than Pioneer brands 3320 and 3165. The experimental synthetic Syn 3I was very similar

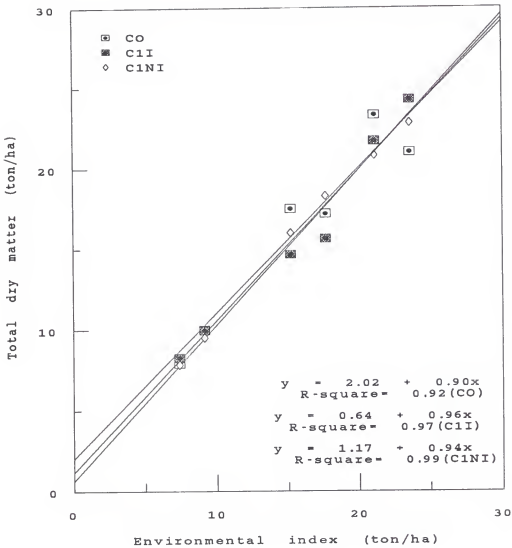

Figure 18. Stability analysis for total dry matter of CO in comparison with $C1_I$ and $C1_{NI}$ tested in irrigated and rainfed environments in 1993, Gainesville, FL. $C1_I$ = Average of Pop 2 and Syn 2I; $C1_{NI}$ = Average of Pop 3 and Syn 2NI.

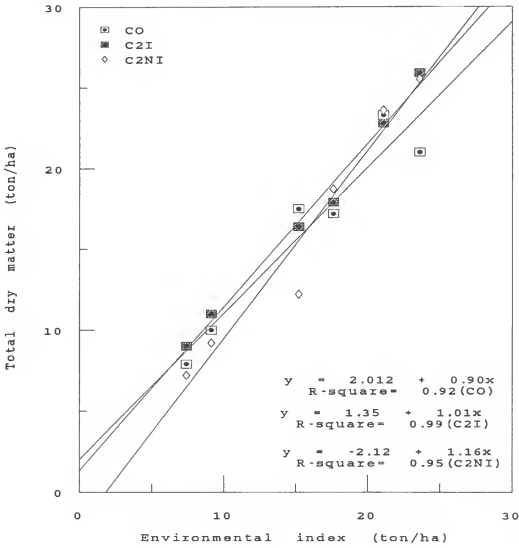

Figure 19. Stability analysis for total dry matter of CO in comparison with $C2_I$ and $C2_{NI}$ tested under irrigated and rainfed environments in 1993, Gainesville, FL. CO = Pop 1; $C2_I$ = Syn 3I; $C2_{NI}$ = Syn 3NI

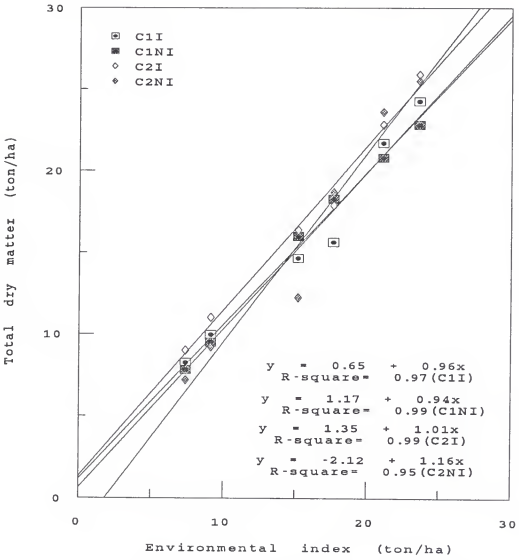

Figure 20. Stability analysis for total dry matter of cycles C1's in comparison with cycles C2's tested under irrigated and rainfed environments in 1993, Gainesville, FL. $C1_I$ = Average of Pop 2 and Syn 2I; $C1_{NI}$ = Average of Pop 3 and Syn 2NI; $C2_I$ = Syn 3I; $C2_{NI}$ = Syn 3NI.

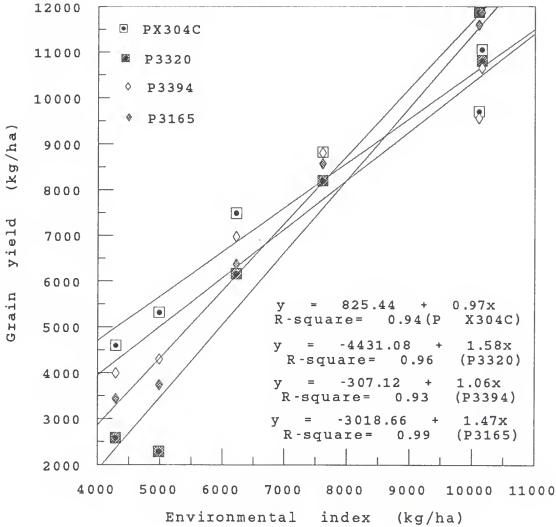

Figure 21. Stability analysis for grain yield of the hybrids used as checks to evaluate the experimental synthetics developed from a full-sib family selection (1993).

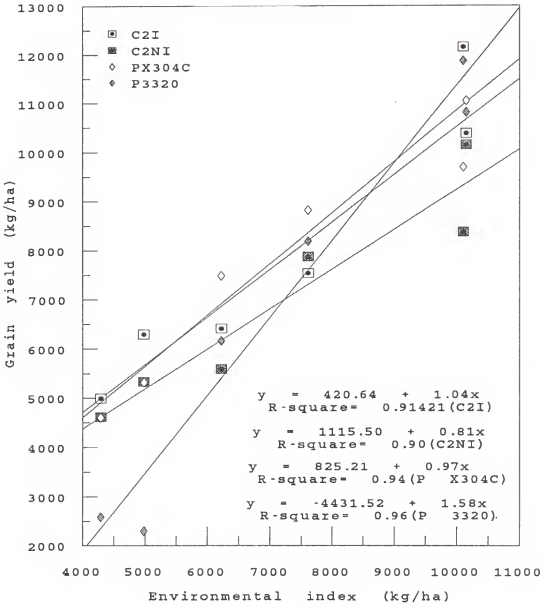

Figure 22. Stability analysis for grain yield of the experimental synthetics in comparison with that of a temperate and a tropical hybrids (1993). $C2_I$ = Syn 3I; $C2_{NI}$ = Syn 3NI.

to the hybrid check Pioneer brand X304C, which is preferred particularly for late plantings in Florida (Figure 22). Both (Syn 3I and Pioneer brand X304C) had respective regression coefficients (b) of 1.04 and 0.97. Syn 3NI was the most stable with a b value of 0.81.

Bolanos and Edmeades (1993a) obtained an increase of 108 kg ha^{-1} $cycle^{-1}$ in grain yield after eight cycles of selection for drought tolerance in a lowland tropical maize. No effect of selection on biomass production was observed and the increase in grain yield was interpreted as a result of a gain in HI. In our program, gains (increases) were obtained for grain yield, total dry matter, and HI for selection conducted under either irrigated or rainfed conditions by selecting under irrigation. Having the rainfed selections under irrigation resulted in a linear decrease in grain yield and HI due to a too high linear increase in total dry matter. However, under nonirrigated conditions, the rainfed selections exhibited a linear increase in HI by maintaining grain yield constant and decreasing total dry matter. Further selection needs to concentrate more on a better adjustment of total dry matter under rainfed conditions. Total dry matter and HI were both highly correlated with grain yield in the Florida environment, with an optimum particularly important under irrigation. Sinclair et al. (1990) observed that reductions in maize grain yield in the Florida environment were due to

decreases in biomass production as a result of mild drought stress.

The rates of improvement were much slower under the rainfed site due also to a differential rainfall in 1991 and 1992, the latter providing more severe stress leading to a better selection, reflecting drought tolerant mechanisms. Bolanos and Edmeades (1993b) concluded after eight cycles of full-sib recurrent selection for drought tolerance that selection for reduced anthesis-to-silking interval or flower delay under carefully managed moisture stress imposed at flowering may provide an effective and relatively rapid way to a higher and more stable grain yield and to higher HI in lowland tropical maize. Flower delay under stress was not an important factor correlated with grain yield within our population in Florida since no control over the amount and timing of rainfall was imposed in the rainfed site. Our goal was to increase yield under drought without sacrificing too much of the yield potential of the original population.

Syn 3NI was highly productive under the irrigated March planting with similar grain and biomass yield as Syn 3I. However, Syn 3I outyielded Syn 3NI in good environments, but produced similarly under bad environments as revealed by stability analyses. These analyses also showed that Syn 3I was comparable to the Pioneer brand X304C, the latter being the preferred variety for late plantings in Florida.

CHAPTER VI
SUMMARY AND CONCLUSIONS

The interest in double cropping corn (Zea mays L.) in the Southern USA and similar areas of the world makes breeding corn for drought tolerance essential and a viable alternative to achieve stable yields, as drought along with high temperature and insects are the major constraints in these water-limited environments. To accomplish these objectives, two cycles of a full-sib recurrent selection program were completed (1991-1993) at the University of Florida within a tropical maize population.

Genetic variation existed for yield and the other traits measured, under irrigation or nonirrigated conditions, within the population of full-sib families tested. Sufficient variability existed for continued progress under irrigated and nonirrigated conditions. However, larger values for heritability and for expected progress were obtained in the irrigated environment due to greater genetic variance. For grain yield, heritability estimates were 0.65 and 0.57 in 1991, and 0.59 and 0.47 in 1992 for the irrigated and nonirrigated environments, respectively. Heritability values for total dry matter were 0.67 and 0.63 for the respective irrigated and rainfed conditions in 1991.

Phenotypic correlations revealed that the drought susceptibility index based on grain yield was negatively correlated with grain yield and total dry matter under the nonirrigated environment, with r = -0.56 and r = -0.37, respectively. Flower delay was not correlated with yield under stress, and was not found to be a important component in our breeding program, as it was observed in others (Bolanos and Edmeades, 1993). Plant and ear height were positively correlated with grain and total plant yields under stress but negatively correlated with these traits under irrigation. Some of the families with high yield potential were found to be among the highest yielding families under stress in 1991 (r = 0.55** for grain yield; r = 0.24** for total dry matter). High and positive correlations were found between grain yield and total dry matter in 1991 under irrigated (r = 0.64**) and nonirrigated (r = 0.46**) environments. This suggested that materials with greater biomass production were able to partition more dry matter to the ear. Yield in cereals depends on the meristematic activity of organs like tassel, leaves, tillers, and ears which may compete with each other for carbohydrates at different stages of the plant development.

A more severe drought stress was obtained for the year 1992. This resulted in a reduction of the mean grain yield of the population selected under rainfed condition from 5090 kg ha^{-1} in 1991 to 4250 kg ha^{-1}. For the irrigated environment,

mean population grain yield was increased from 6367 kg ha^{-1} to 7438 kg ha^{-1}.

Linear responses $cycle^{-1}$ for grain yield was 606 kg ha^{-1} (7.22%) and 153 kg ha^{-1} (2.55%) with the irrigated selections under irrigated and nonirrigated conditions, respectively. The corresponding responses were -224 kg ha^{-1} (-2.67%) and 9.5 kg ha^{-1} (0.16%) $cycle^{-1}$ for the nonirrigated selections. Total dry matter increased by 0.90 ton ha^{-1} (4.97%) and 0.65 ton ha^{-1} (3.59%) $cycle^{-1}$ for the respective irrigated and nonirrigated selections tested under irrigation. A linear decrease of -5.28 ton ha^{-1} $cycle^{-1}$ was obtained with the nonirrigated selections under rainfed conditions. Harvest index increased by 2.22 and 1.19% $cycle^{-1}$ when testing the irrigated selections under irrigated and nonirrigated conditions, respectively. A loss of -3.33% and a gain of 5.95% were obtained by testing the nonirrigated selections under irrigated and nonirrigated conditions. Having the rainfed selections under irrigation resulted in a linear decrease in grain yield and HI due to a too high linear increase in total dry matter. However, under nonirrigated conditions, the rainfed selections exhibited a linear increase in HI by maintaining grain yield constant and decreasing total dry matter. Further selection needs to put more emphasis on a better adjustment of total dry matter under rainfed conditions.

No correlated changes in plant height were obtained for selecting for high yield in the irrigated site. This lack of response resulted from a low association of plant height with grain yield obtained under the high moisture environment. An overall decrease in plant height of -3.50 m (-1.49%) $cycle^{-1}$ was realized with the rainfed selections in nonirrigated environments. No significant change was observed for ear height under irrigation. A similar decrease of -1.85% $cycle^{-1}$ was measured for the selections with and without irrigation tested under nonirrigated plantings.

Leaf area index was increased by 1.72% and 2.68% $cycle^{-1}$ by selecting for high grain yield under irrigated and nonirrigated conditions, respectively. However, a decrease of -2.13% $cycle^{-1}$ when the irrigated selections was planted under nonirrigated environments. Leaf numbers were not altered from selecting under irrigated or nonirrigated conditions.

The experimental synthetics Syn 3I (selected under irrigation) and Syn 3NI (selected without irrigation) were similar for yield potential under poor environments, but differed under good environments in favor of Syn 3I. Syn 3I was very similar to the hybrid check Pioneer brand X304C, which is preferred particularly for late plantings in multiple cropping systems in Florida. Both (Syn 3I and Pioneer brand X304C) had respective regression coefficients (b) of 1.04 and 0.97. Syn 3NI was more stable with a b value of 0.81. The temperate hybrids, Pioneer brands 3320 and 3165 would be

considered unstable cultivars with respective b-values of 1.58 and 1.47, giving low yields in poor environments but high yields in favorable environments. Pioneer brand 3394 was more stable with a b-value of 1.06.

The genetic variability of the two populations (irrigated and nonirrigated) was maintained for grain yield and total dry matter after the two cycles of selection. This suggests that further progress in selection for yield and drought tolerance is still possible. More effort needs to be done to further improve grain yield under drought stress. Multilocation trials (including locations and years) with a range of available moisture would give a better assessment of the experimental synthetics under varying environments. The year-to-year variation would also be taken into account. Further trials could explore the relationships between yield and its components. The two populations could also be exploited for line and hybrid breeding.

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BIOGRAPHICAL SKETCH

Serge Jean-Louis Edmé was born on 26 February 1957 in Les Cayes, southern region of Haiti. There, he attended primary and secondary school until 1976, when he enrolled with the University of Haiti. He completed his B.S. from the School of Agronomy and Veterinary Medicine of Haiti in 1980.

Edmé worked for 8 years in extension and research for the Ministry of Agriculture, Natural Resources and Rural Development (MARNDR) of Haiti. After a six-month training (from May to November of 1983) at the Centro Internacional de Maiz y Trigo (CIMMYT) in maize research and production, he joined a Farming System Project involved in carrying research to farmers' fields and the production of seeds in Haiti.

For the period of 1987-88, Edmé was in charge of field operations of a research project, the Agricultural Development Support Part II, in the Les Cayes region. During this period he was granted a scholarship from CIMMYT to pursue a master's program in the United States. He entered the graduate program at the University of Florida in January 1989 and completed his Master of Science studies in 1990 in agronomy (seed technology). Upon completion, he was awarded a three-year fellowship from the Graduate Minority Programs from the

University of Florida to pursue a Ph.D. program, starting in 1991. His Ph.D. work emphasized breeding tropical corn for drought tolerance for improved yield stability in drought-prone environments. He was also granted a research grant from Pioneer HI-Bred International to cover field work expenses, and book allowance.

Edmé is married to Marthe Jocelyne.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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